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OF TO-DAY

CHARLES W. DOMVILLE-FIFE

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TEACHING THE CREWS OF BRITISH SUBMARINES THE USE OF THE ESCAPE DRESS

This photograph shows a man practising getting into and out of the air-lock which is fitted in all modern British submarines. The "dummy" air-lock is then lowered to the bottom of the tank, and the "pupil" emerges into the water, makes his way through a miniature submarine and emerges by way of the conning-tower.

SUBMARINE ENGINEERING OF TO-DAY

By

CHARLES W. DOMVILLE-FIFE

With 90 Illustrations & Diagrams

PHILADELPHIA
J. B. LIPPINCOTT COMPANY
LONDON: SEELEY, SERVICE & CO. LTD.
1914

D

SUBMARINE ENGINEERING OF TO-DAY:

A Popular Account of the Methods by which Sunken Ships are Raised, Docks Built, Rocks Blasted Away, Tunnels Excavated, and many other Feats of Engineering beneath the Surface of the Water, together with a Description of the Latest Types of Submarine Boats

By

CHARLES W. DOMVILLE-FIFE

Author of "Submarines of the World's Navies," &c.

With 98 Illustrations & Diagrams

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PREFACE

SUBMARINE engineering has in the past been divided into branches of civil and marine engineering, naval construction, and seamanship, with the necessary accompaniments of mechanics, physics, and chemistry. It is, however, in reality, with some modifications and additions, the science of applying many forms of land engineering and construction to under-water work, hence it naturally finds a place in the series of volumes dealing with the "Science of To-day."

There is, however, another and an entirely different aspect of submarine engineering, viz. its use in modern naval warfare, which must certainly receive attention here on account of its rapidly growing importance and its wide future possibilities. That warfare has become largely a matter of engineering is a fact beyond dispute, and it is equally as true to say that under-water fighting is almost entirely so. The navies of the world include hundreds of under-water fighting ships of no mean size and power, armed with torpedoes and guns. Every harbour, channel, and waterway of strategic importance has its submarine mine defence; every warship its torpedoes, submerged tubes, submarine signalling appliances, and complement of trained divers; every naval base its submarine floating dock, and every naval service its corps of submarine experts—and

all this is a portion of the science which is so rapidly increasing in both commercial and national importance.

In the present volume I lay no claim to completeness, but rather have I endeavoured to cover the vast and ever-widening field by selecting those subjects which form the backbone of the work performed by the submarine engineer. To the professional reader I make no appeal, for to him many of the descriptions and diagrams would necessarily lack detail, completeness, and exactitude; but to the general reader who may desire to gain an insight into this branch of scientific engineering, unhampered by technical terms, mathematical formulæ, and wearisome detail, only to be mastered by long study, I venture to hope this work may prove both interesting and useful.

I have received much help from many of the large engineering firms and journals of England and America, to whom I now tender my acknowledgments. I wish specially to thank Mr. R. H. Davis and Messrs. Siebe, Gorman & Co. for the quantity of valuable material and photographs so kindly placed at my disposal, also the *New York Herald*, the Submarine Signal Company, and the Editors of the *Daily Mail* and *Evening News* for permission to incorporate some articles written for their respective journals, by myself, in the present work.

C. W. D.-F.

WESTMINSTER.

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SUBMARINE ENGINEERING OF TO-DAY

CHAPTER I

THE MODERN DIVER AND HIS DRESS

EVERYTHING that pertains to the sea—that vast, unstable body of fluid, so deep, mysterious, and easily influenced by the breezes of heaven—appeals strongly to the imagination, and is of paramount importance to islanders who cannot leave their country without the aid of ships.

Kipling has immortalised the man-of-warsmen, the builders of bridges, and others, and Louis Stevenson made famous the plucky deeds of lighthousemen, yet the lonely, dangerous work of those who descend into the deep is much more romantic and far less known than any other vocation connected with the sea.

It must, however, be confessed that modern invention has done much to mitigate the dangers and difficulties which formerly beset the carrying out of submarine operations.

If submarine engineering—so wide in its ramifications and intricate in its problems—rests theoreti-

cally with the civil engineer, it is certain that in practice it rests with the diver and his appliances. Without him no large or difficult task could be accomplished. The deep-sea diver must be as sound in wind and limb as he is skilled and courageous.

The art of deep-sea diving is almost as old as the human race. Mention of its employment occurs in Homer's *Iliad*, though Thucydides is the first to state that divers were employed during the siege of Syracuse to destroy the submarine barriers which had been constructed to prevent the entry of Grecian war vessels. But these were examples of unassisted diving. The earliest record of mechanical appliances being used to enable men to remain under water for some considerable time occurs in the works of Aristotle, although it was not until 1819 that a really practical dress was invented by Augustus Siebe, founder of the now well-known firm of Siebe, Gorman & Co., Limited.

Although jealous of any encroachment on the space available for the treatment of the wonderful appliances used in modern submarine engineering, it may be of interest to give here a description of Siebe's epoch-making inventions.

After carrying out many experiments, Augustus Siebe invented what is known as the "open dress" in 1819. This consisted of a metal helmet and shoulder-plate fixed to a watertight jacket, beneath which, fitting closely to the body, was a combination suit reaching to the armpits. The helmet was fitted

with an air-inlet valve to which was attached one end of a flexible pipe, the surface end being connected with a pump for supplying a constant stream of compressed air to the diver. This dress was modelled on the same principle as the diving-bell. The air, which kept the water from rising between the outer jacket and under garment, forced its way out and escaped to the surface.

The great defect in this dress was that its wearer, when under water, was compelled to maintain an upright, or but very slightly stooping position. If he accidentally stumbled—a by no means unlikely contingent on a rocky sea-bed—the water filled his dress, and there was great danger of his drowning before those tending the "life-line" above could be made aware that something was wrong, and haul him to the surface.

To overcome this and many other defects, Siebe continued to carry on experiments for nearly ten years, and in 1830 his efforts were crowned with that complete success which delights the heart of an inventor, for in that year he introduced his "closed dress" in combination with a helmet fitted with an inlet valve and one for regulating the outlet of superfluous air.

Although vast improvements in diving dresses have been made since Augustus Siebe's death in 1872, it is this principle which has been in use the world over up to the present day.

The importance of this invention, with its many modern improvements, may be gathered from the

fact that the helmet, or independent diver, is quite indispensable in all forms of harbour, dock, pier, and breakwater construction, bridge building, wreck-raising, recovering sunken treasure and cargo, pearl and sponge fishing, and for use on shipboard in cases of emergency. Almost every ship in the British, and in most foreign navies, carries at least one complete set of diving apparatus for clearing entangled propellers, cleaning the ship's hull below the water-line, clearing choked valves, repairing damage, and recovering lost anchors, chains, and torpedoes.

When it is considered that divers at a depth of only 33 feet under water have a total pressure of about 64,800 pounds on their whole bodies it is not to be wondered at that not only are certain types of apparently healthy men debarred from ever becoming divers, but that even the strongest and most courageous need many ingenious mechanical and scientific aids and safeguards to enable them to carry on work in the submarine world.[1]

What is it that prevents a man when subjected

[1] It is important to notice that when referring to "pressure" it is usual to ignore the ordinary atmospheric pressure, or weight of the miles of air above the earth which is continually pressing down upon it. This amounts to fifteen pounds per square inch. When, however, the words "total" or "absolute" pressure are used the atmospheric pressure is included in the calculation.

The superficial area of the ordinary sized man's body is about 2160 square inches. From this the pressures to which the *whole body* of a diver is exposed at various depths can be easily reckoned on referring to a later table. In most cases the calculations have been made exclusive of the atmospheric pressure, in accordance with the practice of submarine engineering.

to such enormous pressures from being crushed, or his joints dislocated, as would undoubtedly be the case were such a weight passed over his body on dry land?

To the non-technical reader this may appear a simple and quite unnecessary question, the answer naturally being that a diver is protected from this pressure by the dress he wears. This, however, is not the case. His dress, with the exception of the helmet and breastplate, being made principally of rubber and canvas, protects him but little from this pressure, which, however, is so uniform and equable, and is exerted on the whole exterior of a diver's body, that no dislocation of his frame is caused by it. Were an equal pressure, or anything approaching it, to be exerted on one part of the diver only, his body would be crushed in like an egg-shell, but the pressure on one part tends to counteract the pressure on another part, hence no dislocation of joints is caused. Nevertheless, the diver's whole exterior is subject to these enormous strains, which would still be unsupportable were it not for the fact that, although the walls of the body bear the strain, they are supported internally by an almost equal pressure of air and other elastic fluids, which constantly endeavour to expand the more they are compressed. Consequently the air, which is forced down the pipe supplying the diver when under water, is at a pressure equal to or slightly in excess of that of the outside water. The result of this is that he inhales air at a high pressure, which sup-

ports his frame against the crushing effect of the outside water. When it is also considered that the membraneous and other solid parts of a human body are of such a very firm texture that, providing the pressure is exerted in equal force on all parts, they are able to sustain without injury a pressure which, if given in figures, would scarcely be credited by any save the medical man, scientist, and engineer.

So important is this scientific or human problem in diving that I must deal fully with its various phases before passing on to describe the mechanical aids and safeguards which form the stock-in-trade of the deep-sea diver.

It has now been demonstrated that although divers actually bear the pressure exerted by the water, which may be said roughly to increase at the rate of 4½ lb. to the square inch for every ten feet descended below the surface, their bodies are supported internally by an equal pressure of air, which is supplied them from above, and the water exerting a pressure equally on all parts of their frames, no dislocation of joints is caused. There are, however, rules laid down by nature which can seldom be transgressed by men who work subjected to these pressures beneath the sea. When a diver undertakes his first descent he usually suffers from nervousness, which causes a peculiar gasping for breath and increased pulsation of the heart, often so acute that it is inadvisable for him to proceed until this unpleasant feeling has been partly over-

come by watching others descend, and by going himself a few feet under the surface and returning. Even when this curious feeling of excitement and want of air has been almost overcome it is distinctly advisable that the novice should descend very slowly, swallowing saliva and halting every few seconds to recover nerve and equilibrium.

For at least two hours before commencing operations a diver, unless he be an old hand, is seldom allowed to take any kind of food except perhaps a few biscuits and a small quantity of liquid; and when returning to the surface his progress is slow, for if the brain is suddenly relieved from pressure a rush of blood to the head might take place with serious consequences. Even a man with a strong constitution should not ascend to the surface at a rate more rapid than two feet per second.

From the foregoing it will be realised that only strong and thoroughly healthy men can ever become professional divers, though be it understood so perfect is the modern dress that almost anyone of sound constitution may descend in comparatively shallow water without any fear whatever of unpleasant results. It is, of course, necessary that they do so under the guidance of an expert diver with qualified assistants on the surface.

The dress of the modern deep-sea diver may be divided into three parts, exclusive of such accessories as the pump, air-pipe, telephone, and life-line. The dress itself is made of sheet india-rubber faced both inside and out with specially tanned twill, and

is of great strength and durability. As will be seen in the diagram and illustration, it is a complete watertight combination suit with cuffs of vulcanised rubber which are made to fit tightly round the wrists by the addition of rubber rings. There are two collar pieces; the outer one, which is vulcanised, is fixed outside the breastplate and forms a watertight joint, while the under one pulls up round the neck. The breastplate, like the helmet, is of tin-plated copper, and is held to the rubber collar of the dress by screws and nuts, which are adjusted so as to press the rubber collar between an outer metal flange and the breastplate itself, thus forming a watertight joint. The two little studs with holes through them in the front of the breastplate are for fixing the weights in the manner shown in the diagram (Fig. 10); and on the circular neck of the breastplate the helmet is screwed just before the diver requires to descend.

The copper helmet has two oval-shaped plate-glass windows in the sides, and a circular one in the front. Although of very thick plate glass and exceedingly strong, as they require to be to withstand a very great pressure, they are protected from blows by metal guards. The front window, which, like the other two side ones, has a brass frame, can be unscrewed and taken out so that when on the surface the diver can breathe and talk without the aid of the air-pump and telephone.

A specially designed outlet valve at the side of the helmet allows the foul or superfluous air to

escape, at the same time preventing any water from entering. It is placed in a convenient position so that the diver may regulate, by means of a cock, the pressure of air inside his dress and helmet, which varies according to depth. By this means

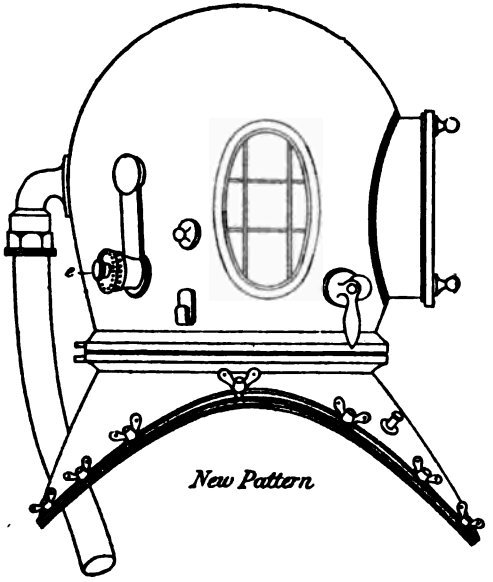

FIG. 1.—Diver's Helmet, showing exterior arrangements of Siebe-Gorman's patent adjustable air-outlet valve.

the diver is also able to descend or ascend at pleasure without any assistance from the surface, and also to remain suspended in mid-water if he so desires—in other words, to regulate his buoyancy.

The metal pipe at the back of the helmet, to which is attached the rubber pipe leading to the air-pump on the surface, possesses an air-inlet valve so arranged that although it allows air to enter,

none could under any circumstances escape. This is important, for if the rubber pipe carrying the supply of air from the surface were by some means severed or damaged, although the actual supply would cease there would be sufficient air remaining

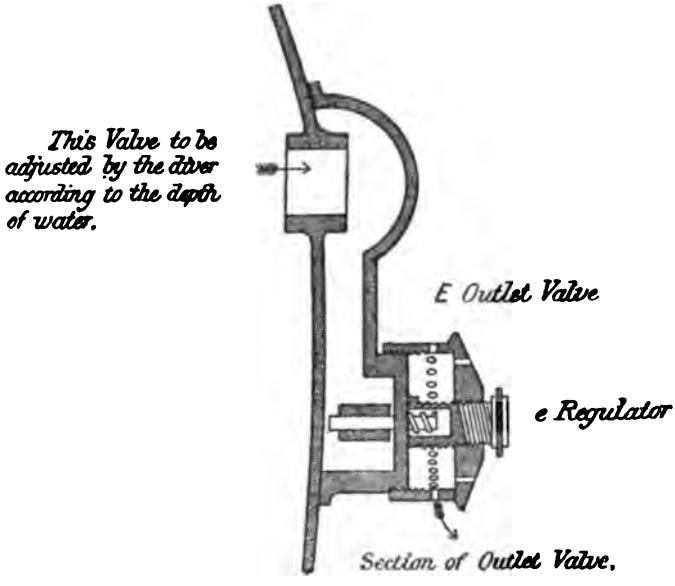

FIG. 2.—This shows the mechanism of the adjustable air-outlet valve.

in the helmet and dress to allow the diver to reach the surface. The helmet is also fitted with conductors by means of which the air supply is conveyed over the three glass windows before being deflected on to the diver's face for breathing, thus preventing the glasses from becoming obscured by the condensation of the diver's breath.

The weights carried by the diver to overcome

the natural buoyancy and so enable him to sink are two heart-shaped slabs of lead weighing 40 lb. each. They rest on the back and front of the breastplate, while the stout leather boots, which are laced on over the foot-piece of the watertight dress, have leaden soles weighing 16 lb. each.

It may appear curious, with such an enormous weight of metal, that a man can move about with comparative ease when under water. It is true he cannot walk far on the surface, but they are carried to overcome the natural buoyancy of the human body, and, consequently, when once a diver is below the surface, the tendency to rise counteracts the depression of the weights, which then hamper his movements no more than a light overcoat does on the surface.

Although there are several other types of diving dress which differ slightly from the one just described, they are all on the same principle, and need not be detailed here. In addition to his dress, however, the diver carries many accessories, such as a telephone, electric lamp, and knife. The miscellaneous items of a diver's gear, being of considerable importance, are described in a separate chapter; but before donning a diving dress and going down on to the sea-bed of the English Channel with the object of gaining an insight into the practical work of a diver, it may be of interest to give here a complete list of the apparatus required by a diver for deep-sea work.

Set of Diving Apparatus, complete in all respects, for one Diver for Deep-sea Work.[1]

(1) Latest improved patent three-cylinder single-acting diving air-pump, in teak chest, including pressure gauge, tools, and spare parts.

(2) A strong chest containing one of the latest safety diving helmets and corselet (as described).

(3) A seaman's chest fitted especially to contain: 150 feet, in three 50-feet lengths, of air-piping with gun-metal couplings; two complete diving dresses, which should be used alternately; one strong canvas overall dress, for protecting the diving dresses from undue chafing in rough and rocky places; one pair of diving boots, with metal toe-caps; a pair of lead weights; a strong leather waistbelt, with brass buckles, and fitted with gun-metal pipeholder for securing the air-pipe in its proper position; a diver's knife in metal case; a helmet nut-spanner; and 180 feet of life-line containing telephone wire.

(4) The following special underclothing is also necessary: 3 heavy hand-knitted woollen guernseys; 3 pairs heavy knitted drawers; 3 pairs knitted stockings for use inside the dress, and 1 additional pair for use outside; 1 woollen cap, and 1 neckerchief.

(5) The following tools and spare parts also form a necessary part of a diver's equipment:

[1] By kind permission of Siebe, Gorman & Co.

1 pair of metal cuff expanders; 1 tin of specially prepared india-rubber solution for repairing diving-dresses; 1 sheet of prepared rubber cloth for patching; 1 spare brass screw-frame for helmet, with glass and guards; 2 spare glasses for helmet; 12 vulcanised india-rubber cuff rings.

With this apparatus on board and two experienced divers, the large boat from which the operations are to be conducted is towed out to sea. The object of this expedition is to examine the iron chain and shackle of the moorings of a buoy which marks the fairway between two sand-banks. It is situated about one mile from the shore, yet the water is only just over 30 feet deep, owing to the rise caused by the sand-banks.

The sea is smooth, and when the scene of operations has been reached, an iron ladder, provided with stays to bear against the side of the boat, is hoisted over the gunwale and fixed in position. Many experienced divers prefer to descend from the bottom rung of this ladder on to the sea-bed by means of a rope weighted at the lower end to keep it down; but the easiest method for the novice is to go down by a rope-ladder with ash rungs, or "rounds" as they are called in nautical parlance, and in this case, the water being comparatively shallow, a ladder of this kind is fixed to the bottom of the iron one and its ends weighted so as to rest on the sea-bed.

While this is being done the air-pump, which will be described in a future chapter, is being securely lashed in its proper position—facing the head of the ladder—and the two divers are being dressed, as one is to remain in readiness to descend to our aid should anything untoward occur.

We now commence to don our dresses, putting on, first, a thick woollen guernsey and pair of drawers, which are carefully fastened by a tape round the waist to prevent them from slipping down, then a pair of very thick woollen stockings. If the water into which we are descending had been very deep several suits of wool or flannel would have been added to our stock of under-clothing in order to relieve the great pressure; but as it is comparatively shallow, these additional garments are not necessary, and it now only remains for us to put on a thick woollen cap and shoulder-pad, which eases the weight of the breast-plate and helmet, and to don the diving-dress already described.

The last preparations before we descend are best described in the instructions given to divers by the well-known submarine engineers, Messrs. Siebe, Gorman & Co.: "The rings are passed over the cuffs, and the sleeves of the overall (if one is used) are drawn down to cover them. If gloves are to be used, the rings will be put on over them, as well as the cuffs. The helmet (without the front bull's-eye) is then put on; but before doing so, the attendant should blow through the outlet-valve of

the helmet; he can do this by placing his head in the interior, and with his mouth to the hole where the air escapes blow strongly; if in proper working order, the valve will vibrate. A loop of the life-line is placed round the diver's waist, the line being afterwards brought up in front of the man's body and secured with a piece of small rope passing round his neck, or to the stud on the helmet. The waist-belt is buckled on with the knife on the left side, the end of the air-pipe being passed from the front, through the ring on the belt on the man's left, and up to the inlet valve on the helmet, to which it is secured; the upper part of the pipe is then made fast by a lashing to the stud on the left of the helmet. The diver then steps on to the ladder, and two men are told off to man the pump."

The front and back weights are then fixed on to the breastplate and—"when the signalman is sure that all is right, and that the diver understands the signals (or the telephone is properly adjusted)—he gives the word 'pump,' and screws the centre bull's-eye into the helmet securely; this done, he takes hold of the life-line and 'pats' the top of the helmet, which is the signal for the diver to descend."

Rising with difficulty, owing to the weights, helmet, and heavy, leaden-soled boots, we follow the expert diver over the gunwale of the boat. It is an exciting moment, for we are about to enter a new world, unknown to all save the diver and the crews of submarine boats. As we slowly descend the iron ladder and the water rises around

us, bringing with it a buoyancy which lifts, first, the weights from our feet, and then, when the wavelets commence to splash against our helmets, the load of lead from off our shoulders.

When the water has closed overhead we halt for a few moments to satisfy ourselves that everything is correctly adjusted, and that no water is leaking through the joints in our armour. The sunlight penetrates deep into the water, and we can see plainly the shadowy iron stays as we slowly descend, step by step, until our feet rest on the first rungs of the swaying rope-ladder which is to take us down on to the sea-bed.

The light grows a little more dim, but objects can clearly be distinguished. A curious feeling of oppression and a humming noise in the ears is now felt, and according to previous instructions we ascend a few feet, swallowing saliva several times, and then continue the descent. The noise in the ears and feeling of oppression slowly gives place to a sense of security as our feet touch the sea-bed.

On arriving at the bottom the diver gives one pull on the life-line to notify those in the boat above that we are "all right," and then attaches to the ladder one end of a rope, called the "ladder-line," which he holds coiled in one hand, the other end being looped over his wrist. As he moves forward, away from the ladder, he allows this line to uncoil behind him, so that when it is desired to return no difficulty shall be experienced in finding the ladder.

By permission of *Messrs. Siebe, Gorman & Co., Ltd.*

A MODERN DIVING DRESS

The trousers are laced tight to prevent the diver from being capsized or blown upside-down to the surface by an accumulation of air in the lower part of the dress.

The Modern Diver and his Dress

The most noticeable feeling when on the sea-bed is one of peculiar lightness and instability, combined with a feeling of powerlessness and insignificance. It is difficult to walk straight, and quite impossible to hurry; and the fact that a diver can exert but little force in pulling downwards, or pushing horizontally, unless, of course, he can fasten himself in some way to the sea-bed, is instantly brought home; while it is extremely difficult to use a hammer effectively, as the force of the blows are minimised to a great extent by the resistance of the water. To carry out even the simple operation of boring an auger hole in a wooden pile, it is often necessary for the diver to lash himself to the pile before he can exert sufficient pressure on the tool. These facts should be borne in mind, for they have no small bearing on the value of pneumatic tools for submarine work.

There is also a curious groping sensation when under water, which causes one to spread out the arms in front, and in this respect it can only be likened to walking in a thick white fog. Yet withal it is by no means unpleasant. The pressure of water about which we have heard so much causes no inconvenience, and, in fact, although we are 32 feet deep and the pressure is about 13 lb. on every square inch of our body, it is scarcely noticeable, except perhaps when breathing very deeply. The air from the surface comes hissing into the helmet, and after passing over the glass windows is deflected on to the face in a cool stream of which there is no lack.

We follow the guide for a few yards and then a large iron chain going slantwise to the surface comes in view. This is the object of our search. The diver now proceeds to examine the chain and the huge shackle which links it to the curiously shaped iron anchor which lies beneath our feet half-buried in the sand.

It may appear unnecessary that a diver should be sent down to periodically examine the moorings of a buoy, but if we consider for a moment the possible consequences to shipping if it broke loose in a gale, it will be realised that such a precaution is amply justified. A vessel might deviate from the proper course and come to grief on the sand-banks on either hand.

When the diver has completed his examination, and in order to do that effectively he is hauled some considerable distance up the chain by those in the boat on the surface which is following our movements, a sharp pull on the life-line attracts our attention. It is the signalman inquiring if we are "all right," and we reply in the affirmative by a similar pull. It may be as well again to quote from the instructions issued to divers, although the new loud-sounding submarine telephone, described in the following chapter, has made many of these instructions almost unnecessary.

"The signalman is the responsible person, and must be very vigilant all the time the diver is down; occasionally he will give one pull on the life-line, and the diver should return the signal by

one pull, signifying 'all right'; if the signal be not returned, the diver must be hauled up. If the signalman feels any irregular jerks, such as might be occasioned by the diver falling into a hole, he should signal to know if he is all right, and if he does not receive any reply, he should haul him up immediately. If the diver from any cause is unable to ascend the ladder, and wishes to be pulled up, he gives four sharp pulls on the life-line. If while being hauled up the diver gives one pull, it signifies 'all right, don't haul me any more.'

"The diver should be hauled up slowly and steadily. If the signalman wishes the diver to come to the surface, he gives four sharp pulls on the line, on which the diver should answer 'all right,' return to the foot of the ladder, and signal to be hauled up."

When the diver has completed his examination of the moorings, we grope our way slowly back to the ladder and commence the ascent, which is accomplished very slowly. At last the bright rays of the sun penetrate the water around, and a few seconds later our helmets rise above the surface and we are hauled ignominiously into the boat.

The "bull's eyes," or front windows, are at once removed from the helmets, the pumping ceases, and we feel the cool sea breeze on our faces.

CHAPTER II

THE SUBMARINE TELEPHONE

THE loud-sounding submarine telephone is one of the most important appliances used in under-water work. It enables attendants and others on the surface to converse freely with divers on the sea-bed; the divers themselves to talk to each other, and the engineer commanding-in-chief to give rapid instructions to his submarine forces, thus insuring their working in unison with those above water. It is also the most admirable safeguard against fatal accidents, as with its aid divers can give warning to those on the surface of impending difficulties and dangers, and immediate action to minimise the peril can then be taken.

Examples of this are frequent in the difficult task of wreck-raising. By some mischance a diver becomes entangled in the wreckage, and his supply of air almost cut off by the presence of a fallen beam or girder on his air-pipe. He is able to telephone to the surface when the ordinary life-line signals described in the last chapter would be quite impossible owing to the entanglement, and help in the form of another diver, who has been waiting dressed in the boat above, ready for such an emergency, is sent at once to extricate him from his dangerous predicament. Again, the use of the submarine tele-

phone is, perhaps, even better illustrated by referring to breakwater construction. On these works divers guide into their proper places the immense concrete blocks lowered by the crane, and in order to do this rapidly and effectively it is absolutely necessary that the divers should be in constant communication with the crane operator so that the blocks may be moved by an interchange of directions into their true positions.

Instances of the practical utility of this apparatus could be multiplied until they embraced almost every form of under-water work, but sufficient has now been said to show its importance to submarine engineering generally. Before commencing to describe the apparatus itself, it may be as well, however, to give here a few particulars of the method employed previous to its introduction, as they are still used when the diving equipment is not of the latest pattern or the work is easy of accomplishment and of little magnitude.

Signalling between attendants on the surface and divers under water is accomplished by pulls on the life-line and air-pipe. Although a convenient code can be easily arranged to suit any particular work, the following is the one usually adopted :—

Life-line

1 pull . . .	"All right."
2 pulls . . .	"According to diver's instructions."
3 „ . . .	„ „ „ (As given by slate-writing or tube.)
4 „ . . .	"Coming up."

Air-pipe

1 pull . . .	"Less air."
2 pulls . . .	"More air."
3 „ . . .	According to diver's instructions.
4 „ . . .	"Haul up diver."

Divers in clear water carry on a conversation with each other by means of small slates, on which they write the sentences instead of speaking them. This method is also occasionally employed in communicating with the surface; but some years ago a patent speaking apparatus was introduced which superseded this very unsatisfactory system. Simplicity of construction was one of its great recommendations. It was nothing more than a speaking-tube, one end of which was fitted into the front of the diver's helmet and terminated in a conveniently situated hearing and speaking attachment, while the flexible rubber tube extended upwards to the surface, where the other end was fixed to the belt of an attendant in the diving-boat. When it was desired to use this appliance in very deep water a disc was also attached to the upper or surface end of the tube, so that there was nothing more than the nominal atmospheric pressure in the tube, and the conversation could be distinctly heard.

The principal drawback to the use of this apparatus was the extra pipe it entailed. It has already been seen that a diver is connected with the surface by a life-line and air-pipe, and it will be readily understood that the addition of yet

another pipe carried with it many disadvantages. The difficulty experienced by divers, when submerged, in making headway against a strong tide or in reaching any position which necessitates dragging their "tails" for any considerable distance, is often very great; as is shown in the description, given later, of work in the flooded Severn Tunnel; and the additional impedimenta necessary restricted the utility of this speaking apparatus to certain kinds of work, such as the surveying of foundations, and harbour, dock, breakwater, and pier construction, where the pipes and lines from the divers come almost vertically to the surface, and but little "dragging" is necessary.

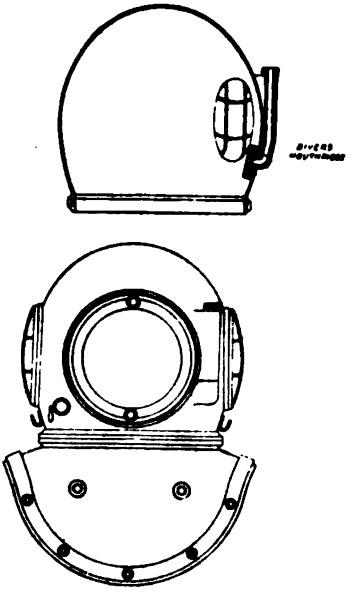

FIG. 3.—Speaking apparatus. (1) Section of diver's helmet, showing arrangement for mouthpiece with metal disc. (2) Exterior of helmet, showing connections for speaking-tube to surface.

Although it suffered from these great disadvantages, this apparatus was very widely adopted as being a real improvement on the old methods of signalling and slate-writing, and in fairness it must be said that it had much to recommend it. There was but little fear of such an extremely simple appliance

getting out of order, and even less of it breaking down suddenly when most required—an important factor which must always be remembered in submarine engineering owing to the lives which so often depend on the reliability of the mechanism employed. It could be fitted to any existing helmet, and its cost was comparatively small. Nevertheless it had a grievous fault, which so restricted its use that Messrs. Siebe, Gorman & Co. continued to experiment—as this enterprising firm are constantly doing in the realms of submarine science—until they produced the perfect instrument in the form of a loud-sounding electric telephone capable of being used in all forms of submarine work.[1]

This apparatus, which in principle is very similar to the ordinary telephone, is shown in the illustration facing p. 38. It consists of an electric battery and small portable exchange, with a combined hand-receiver and mouthpiece for use on the surface. The wires leading down to the diver, or divers, are embedded in the life-line, thus avoiding what was hitherto the great drawback of all these appliances —an additional connection with the surface. The wires connect with a mouth and ear piece fitted inside the helmet, and when the diver desires to ring up the surface he simply presses his chin forward against an electric button, which rings the

[1] In the earliest pattern submarine telephone the wire was embedded in spiral form in the air-pipe, but this proved somewhat unsatisfactory on account of the fact that each length of pipe needed a separate connection, and those without electrical knowledge experienced some little difficulty in making the correct adjustments.

call-bell in the little box-exchange on the surface. He then speaks into the mouthpiece, and the attendant on the surface can connect him with any of the various branches. By this means one diver can speak to another, although perhaps working on different sides of a breakwater or in different holds of a sunken ship. The attendant can ring up any diver and ask him to go at once to the assistance of another diver who may be in danger. An engineer can direct the work of all the divers under water without moving from his office, and can receive timely information from them of any new or important developments. In fact the various connections possible, and uses to which the submarine telephone can be put, are limited only by the size and character of the operations in progress and the number of divers at work.

Its introduction in a thoroughly reliable and practicable form has so far revolutionised submarine engineering as to make it quite impossible to avoid frequently referring to it in future chapters.

CHAPTER III

PUMPS AND AIR-COMPRESSORS

SOONER or later in the course of his work the submarine engineer brings into use nearly all the most modern appliances known to engineering science, and has to deal with a very great variety of materials, both natural and artificial; but of the two elements, air and water, his knowledge can never be too extensive, for they create the ever-present problems of his profession. How best to overcome their gigantic forces and pressures, harness them, and by various combinations of "blood and iron" turn their tremendous powers to good account, is the great object of the submarine engineer, and in the following few chapters I shall deal with the most up-to-date machinery in use for the practical achievement of this purpose.

Perhaps the most useful of all these appliances are the manual pumps, which supply the necessary air to divers while working below the surface. Of these there are many types, but for general purposes in deep or shallow water the one in use on the larger ships of the British Navy is undoubtedly the most efficient and reliable. It is a two-cylinder, double-acting pump, as shown in Fig. 4, and is capable of supplying sufficient air for two divers

working simultaneously in moderate depths, or one diver only in very deep water.[1]

The great advantage of this pump over many other patterns is that when two divers are at work each is in direct connection with one of the cylinders, thus ensuring the constant supply of air to

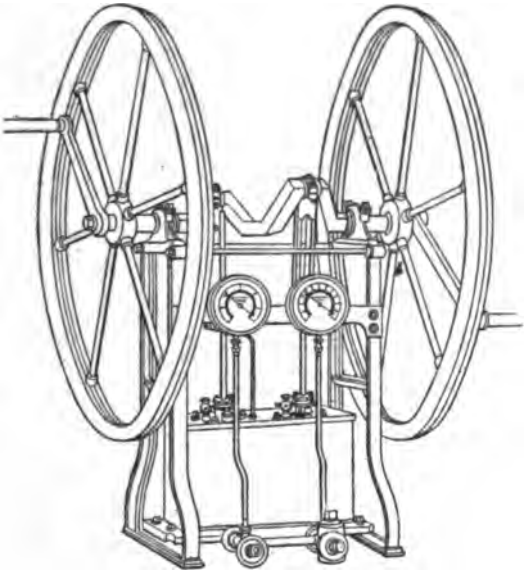

FIG. 4.—Sketch showing diver's two-cylinder air-pump.

both; and when work is being carried on in a depth of water exceeding 90 feet the whole volume of air from both cylinders—8 cubic feet per revolution—is turned into the pipe supplying the one diver only. This is done by a special air-distri-

[1] The reason why a diver requires air at a greater pressure the deeper he descends has already been described in Chapter I.

buting device which will be easily understood by referring to Fig. 5.

This type of pump, which is principally made of best admiralty gun-metal, is securely fitted into a strong teak-wood case, and is worked by two winch

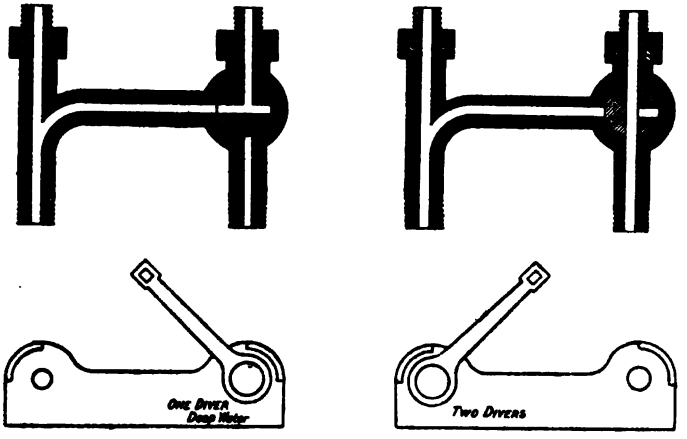

FIG. 5.—(1) Shows the arrangement of the pipes from the pump when both cylinders are switched on to supply the full amount of air to one diver working in deep water; and (2) the position of the lever regulating the distributing device. (3) Shows the air supply divided for supplying two divers in fairly shallow water. It will be seen that in this case each diver is in direct communication with one of the cylinders. (4) Shows the position of the controlling lever in the latter case.

handles and two flywheels. The latter can be easily removed to facilitate transport. Inside the pump case is a box for spare parts and small repairing tools. This pump is capable of compressing air up to 240 lb. per square inch, and is fitted with two pressure gauges, one for each cylinder, which show the depth of water in which the diver is working and the corresponding pressure. By this

means the attendants working the pump on the surface are kept constantly informed of the amount of air required by each diver, and can regulate the supply accordingly by increasing or decreasing the speed at which the pump handles are being turned.

When air is compressed it gains heat from the force used in compressing it, and the cylinders of these pumps are therefore kept cool by water in a copper cistern surrounding them.

There are many other kinds of pumps especially adapted for various purposes. The four-cylinder single-acting type is known as the "pearler," and is largely used on the sponge fisheries of the Mediterranean and the pearling grounds in Torres Strait and elsewhere. It is designed for deep-sea work. There is one, however, of special interest, as it can be dismantled for easy transport over rough or mountainous roads by mules or native carriers in remote places abroad, and is suitable for depths of water down to 50 feet. The heaviest single part weighs only 47 lb., but most of the pieces are very much lighter than this. The whole pump can be fixed up ready for work in a few minutes, and is specially adapted for exploring and prospecting work.

Air-Compressors

The subject of pumps for supplying air to divers naturally leads one to think of the larger power-driven air-compressors used for so many purposes

on all large under-water works. To these is usually attached a reservoir, or receiver (see Fig. 6), for in submarine work it is far safer and more convenient to deliver the air from the compressing engine into a receiver, or intermediary chamber, and to take the air-pipes to the divers, diving-bells, air-locks, and pneumatic tools from this instead of direct from the engine itself, as, by so doing, should any unforeseen accident occur, causing a sudden stoppage of the compressor, there is a sufficient reserve of air in the receiver to bring the men working under water safely to the surface before their supply of air is entirely cut off.

Air-compressors vary in size and design according to the work they are required to perform, and according to the power which is to drive them. Some are operated by steam or electricity, while others are driven by oil-engines. Those mostly used on harbour works for supplying air to large diving-bells, locks, and divers, and on salvage steamers for forcing water out of the flooded compartments of wrecks and pontoons, are, however, almost invariably driven by steam.

To understand these powerful engines, it will be necessary to refer to Fig. 6, which shows the essential parts of a single-cylinder, horizontal, steam-driven, double-acting compressor, mounted on the air-receiver. An engine of this type, measuring 7 feet long by 4 feet wide and 6 feet high, is capable of delivering about 100 cubic feet of free air per minute, which is amply sufficient for

most purposes, although a double-cylinder engine of somewhat larger design, capable of supplying 300 cubic feet of free air per minute is often installed on salvage steamers.

The air-cylinders of these engines are water-jacketed in order to prevent over-heating, as in the

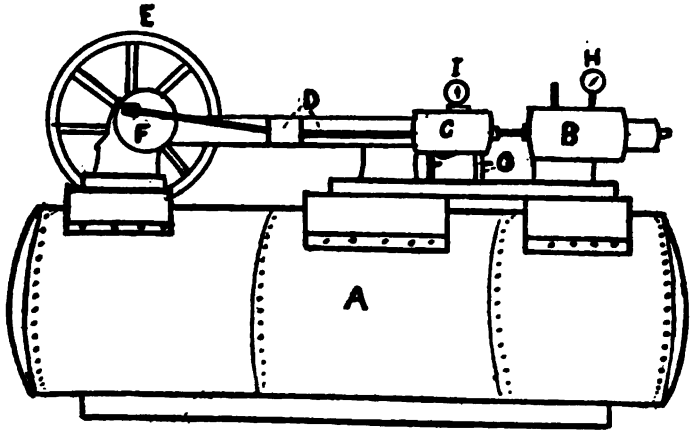

FIG. 6.—Sketch showing principal features of a steam-driven double-acting air-compressor, mounted on an air-receiver. *A*. Air-receiver. *B*. Steam cylinder. *C*. Air cylinder. *D*. Piston and connecting rods. *E*. Fly-wheel. *F*. Eccentric. *G*. Air-inlet valves. *H*. Steam-pressure gauge. *I*. Air-pressure gauge.

ordinary manual pump; but in this case the amount of air compressed is so much larger that the heat generated would soon cause the water in the jacket surrounding the cylinder to boil were it not continually being changed. For this purpose a circulating pump is attached, and a constant supply of water for cooling the air-cylinders insured.

The absence of a boiler for supplying the steam necessary to drive the compressor will probably

have been noticed in Fig. 6. The reason for this is, that in many cases, especially in salvage ships, the steam is obtained direct from the main or auxiliary boilers of the ship's propelling engines or winches, hence a separate boiler is seldom necessary.

There are, of course, very many types of air-compressors of both large and small capacity, which, however, do not call for separate mention here. Now that the system has been outlined on which nearly all these kind of engines work, a brief examination of any particular type will enable the reader to understand its essential features.

Centrifugal Pumps

Now that we have seen how the submarine engineer brings air under pressure into use in his fight with the sea, let us examine the machinery with which he deals as effectively with the water itself.

We are all familiar with the working of an ordinary water-pump, in which the liquid is drawn into a cylinder by the suction caused by the back stroke of a piston or plunger, and retained there until forced out again by the forward stroke, through the provision of suitable inlet and outlet valves. Useful as this old type of pump certainly is for many classes of work, it is quite inadequate for dealing with enormous volumes of water, often amounting in salvage work to thousands of tons,

when the flooded holds of large vessels have to be pumped clear while the wrecks lie many feet deep on the sea-bed. Were it not for the *centrifugal pump*, with its wonderful mechanical simplicity and power, wreck-raising by this means would be practically impossible.

Another problem which has always to be considered in wreck-raising by means of pumps (see p. 100) is the depth from which the water has to be lifted. It is one thing to raise by a continuous stream a ton weight of water to, say, 10 feet, and quite another to suck the same quantity up 50 feet of piping. The power required to drive the pump doing the former work is, naturally, much less than that required to make it perform the latter task at the same speed.

Most people will have noticed that when liquid in a circular vessel is stirred it rises higher up the side the faster it is made to rotate, and the depth in the centre decreases accordingly. This, then, is the principle of the centrifugal pump. It consists of a circular case inside which is a wheel having fans or paddles. This wheel is turned by a steam engine or other power, and the fans impart a rotary motion to the water, sucked in through an inlet in the centre and promptly ejected through an outlet in the circumference. A reference to Fig. 7 will make this quite clear.

In order that the reader may understand the capabilities of these "mighty atoms"—for the largest seldom exceed nine tons in weight, *inclusive*

of the driving engine—it may be stated that an 8-inch pump (*i.e.* suction and discharge pipes 8 inches in diameter) discharges about 330 tons of water per hour when running at full speed, a 12-inch pump 840 tons, and a 24-inch engine is capable of dealing with no less than 3000 tons of water per hour!

The speed at which the inside wheels of these pumps are turned depends entirely upon the work

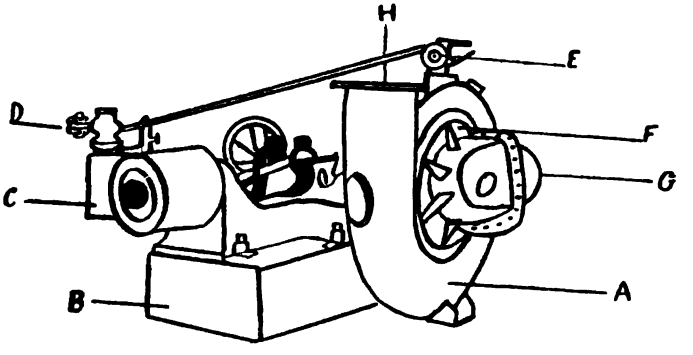

FIG. 7.—Sketch showing centrifugal salvage pump coupled to a steam-engine. *A*. Centrifugal pump. *B*. Bed-plate. *C*. Steam cylinder. *D*. and *E*. Control wheels. *F*. Circular chamber encasing the rotating fans which create the suction. *G*. Water inlet. *H*. Water outlet.

being performed; it may, however, be said to vary from 250 to 400 revolutions per minute.

The simplicity of the mechanism and the strength of the various parts, combined with their relatively low weight, make the centrifugal pump particularly well adapted for slinging on to the deck of a wrecked vessel; and, as an additional facility in working, they may be swivelled to any angle in relation to the bed-plate, so that the delivery branch will face in any desired direction.

The driving-engines of these pumps, when used on salvage vessels, mostly take their steam from the ship's boiler, and even when fitted up on the deck of a wreck are connected to the main boiler of the salvage vessel by galvanised steel piping.

Another feature of the centrifugal salvage pump

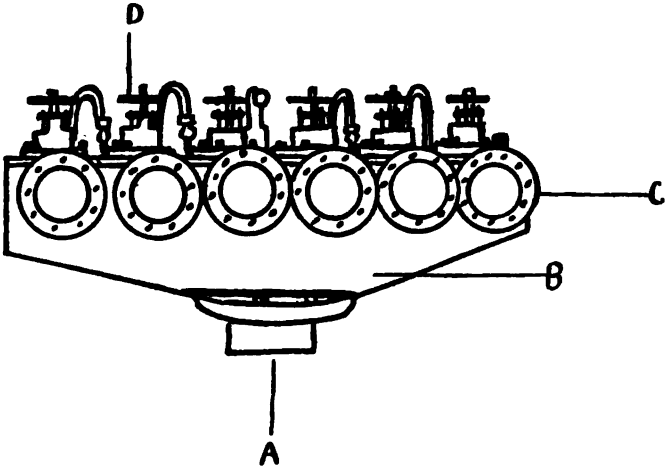

FIG. 8.—Suction-box. *A*. Suction-pipe from centrifugal pump. *B*. Suction-box. *C*. Water inlets from various pipes. *D*. Screw-down valves closing each water inlet and so increasing the suction of those left open.

which must be explained here is the "suction-box" (see Fig. 8), by means of which the main suction pipe is divided into a number of smaller branches to enable the pumping to be carried on in several different places simultaneously. This is an important factor in nearly all salvage operations, as it is frequently necessary to clear the water from the fore and aft holds of a sunken vessel at the same

time. Each opening in the suction-box can be closed by a screw-down valve, so that pumping may be stopped in certain places and thereby increased in others. A simple illustration will make this quite clear. Assuming that there are three separate compartments or holds in the vessel being cleared, and that 100 tons of water per hour is being sucked from each by one centrifugal pump, by stopping the pumping in one of these holds an additional 50 tons per hour will be cleared from the remaining two. Thus when one hold, perhaps smaller than the rest, has been cleared of water, the suction may at once be shut off and the full power of the pump exerted in clearing the water from the remaining compartments.

One of the largest centrifugal pumps in the world is installed on the Rogue River, South Oregon, and is used to operate a battery of hydraulic monitors in the adjacent mines. Although not of the type used in submarine work, as it is designed to deliver the water under pressure, it shows the wonderful development of these engines. It was built by the Byron-Jackson Machine Works of San Francisco, and its capacity is 9000 gallons per minute, or 13 million gallons per day of 24 hours. This enormous volume of water is delivered through a half-mile of pipes, lifted to a height of 100 feet, and forced through two 4-inch nozzles, hurling streams a distance of 500 feet. These streams of water are directed upon the mountain side to tear down the gold-bearing gravel.

CHAPTER IV

SUBMARINE PNEUMATIC TOOLS

ALTHOUGH pneumatic tools generally are not within the realm of submarine engineering, there are various powerful instruments of this kind, such as rock-drills, wire-rope cutters, hammers, and augers, which have become quite indispensable to the under-water worker. The last chapter dealt with pumps and air-compressors in sufficient detail to enable the reader to understand the method and mechanism by which air is supplied under pressure, and the field is therefore clear for a description of these little revolutionising instruments themselves.

Previous to the introduction of pneumatic tools specially adapted for submarine work, the diver was compelled to rely upon various hand implements of similar design to those used on the surface. Now a diver seldom remains under water for more than four hours at a time, and the number of experienced men that can be employed on any large undertaking is, of course, very much less than would be the case were similar work being executed on the surface. For these and other reasons it is highly necessary that divers should be supplied with every possible labour-saving device required in their multifarious work. Again, in deep water violent exer-

tion of any kind is extremely dangerous owing to the pressure, hence tools, such as wire-rope cutters and rock-drills, operated with wonderful rapidity by pneumatic power derived from the surface, have revolutionised certain branches of submarine engineering.

In rock-blasting the submarine drill is almost indispensable. The holes for the reception of the explosive cartridges are drilled by these powerful little instruments, which enable as much work to be done in a few hours as would occupy many days with hand tools. In the removal of wrecks or other obstacles dangerous to navigation, these drills, as well as the pneumatic hammer and rope-cutter, are of great assistance, as it frequently happens, when the obstruction is situated in a busy waterway, that the work of removing it and clearing the channel for shipping has to be accomplished in a minimum of time. Again, when a ship's propellers, or dock gates, become fouled by old wire ropes or chains, the diver has no quicker method of clearing away the obstruction than by using a submarine cutter, which will sever a massive wire rope or iron chain of 6 inches circumference in less than a minute. In naval warfare these wonderful little submarine saws would prove invaluable for clearing away the obstructions used in harbour defence, and for cutting mine-cables and buoy-lines.

The various methods of using pneumatic tools under water will be more fully described in the chapters devoted to the several kinds of work for which

they are mostly employed; but, before this can be attempted, the reader must be made familiar with the appliances themselves.

Of the three kinds of pneumatic drills, the tripod rock-borer is by far the most powerful instrument of its kind used in submarine work. It consists of a heavy steel tripod, fixed to the actual boring machine by clamps. It is held on the sea-bed by the downward pressure exerted by heavy weights attached to the legs of the tripod, and the "thrust" of the drill on the rock in which the hole is being bored is effected and controlled by a powerful spring operated by a crank at the top of the machine itself. The boring machine may be likened to a small steam engine fitted into a watertight metal case, only it is rotated by compressed air instead of steam. The air is conveyed from the surface to the drill by 50 feet lengths of flexible rubber hose, steel wire embedded, and provided with brass connections. The holes bored are usually about 3¼ inches in diameter, which is sufficient for the insertion of the powerful explosive cartridges used in submarine rock blasting.

The rapidity with which a hole of this size is drilled depends entirely upon the nature of the rock, and varies so considerably that no estimate can be given; but the power and speed of this drill is such that thousands of tons of rock have been blasted away by its aid in a few weeks.

A complete submarine rock-drilling plant consists of (1) a double-acting air-compressor, power-driven; (2) a steel air-receiver; (3) the rock-boring machine;

(4) the weighted tripod; (5) lengths of air-hose, according to depth; (6) a set of ten drills specially forged and tempered; and (7) a set of drill-sharpening tools and spare parts for boring machine and air-compressor. The total cost of which, including the compressor and driving engine, amounts to less than £300.

From the large tripod drill we come to the smaller hand drills, which, owing to their light weight and compactness, are even more generally used than the former machine. These, again, can only be likened to tiny steam engines enclosed in a cylinder and operated by air at a pressure of about 80 to 100 lb. per square inch. They are small enough to be handled easily by one man, and are made in two sizes, the largest of which bores a hole in the hardest rock 1½ inches in diameter and 4 feet deep in a remarkably short space of time. These pneumatic hand drills are about £20 apiece, but the whole plant may cost anything from £150 to £200.

Augers operated by compressed air for drilling holes in both wood and iron are also largely used in submarine work. The pneumatic wood-boring tool is capable of making holes up to 2 inches in diameter and 3 feet deep, while drills for iron or steel bore holes of 1¼ inches diameter.

There are various other kinds of boring tools used in submarine work, such as the "torpedo rock-drill," which is really a combination hammer and drill operated by air under high pressure. The

hammer of the largest of these machines gives 650 blows per minute, and the drill is capable of making a hole 2½ inches in diameter and 20 feet deep! Only 12 horse-power is required to drive this wonderful machine in almost any depth of water.

The pneumatic hammer, which is largely used for closing rivets, chipping, caulking, and tube-bending under water, resembles a pistol in appearance, the barrel being a cylinder inside which a small block of steel is forced up and down by compressed air in the same manner as the piston of an engine. Every time the block of steel flies down the cylinder it strikes the chisel or other tool being used. The pressure of air required to operate this instrument is about 100 lb. per square inch, and the number of blows per minute varies. In the lighter forms of work, where the rapidity of the blows is a more important factor than the force behind them, as is the case when closing small rivets, chipping thin steel plates, caulking, or tube-bending, they vary from 1 to 2 thousand per minute; whereas for very heavy work they seldom exceed 600 to 800 per minute. In the larger and more powerful machines the "hammer," or little block of steel, travels further up the cylinder each time in order to gain force.

In salvage work where tangled ropes and chains hamper the operations of the divers, and in cases where wire-ropes have fouled ships' propellers, it is often necessary to cut through the obstructions in several places before the work of salving can

be continued or the vessel enabled to proceed on her way. For these purposes, as well as for use in naval warfare, for cutting the cables connecting submarine mines with the observation stations on shore (see Chapter XXVI), severing at short notice the cables of buoys marking the entrance to harbours

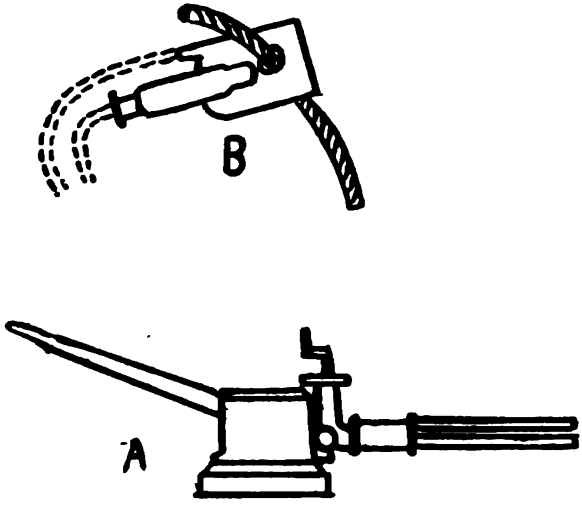

FIG. 9.—The pneumatic wire-rope and chain cutting machine. *A*. Lever controlling compressed air supply (surface mechanism) for operating the submarine cutter *B*.

which might assist the enemy, and for clearing away the chains and booms used in harbour defence, the submarine wire-rope and chain cutting machine is of great utility.

It is a simple and easily operated instrument, which for descriptive purposes may be divided into two parts—the surface mechanism and the submarine cutter (see Fig. 9). The former consists

of a lever which, on being pushed forward, allows the compressed air to travel down two flexible tubes to the cutter, which is nothing more than a very finely tempered steel saw fitted inside a metal case, as shown in the diagram. The rope or chain to be severed is placed through this outer casing, and so brought in direct contact with the edge of the saw. The air is then turned on by the surface lever and the saw rotated at a high speed.

Wire ropes up to 6 inches in circumference, of any make or quality, can be cut through by this marvellous little instrument in about one minute, and chains of much greater circumference in less than two minutes. The saving of labour, a most important consideration in all forms of submarine work, effected by these machines will perhaps be better understood when it is stated that a diver would require several hours to cut a rope or chain which can by this means be severed in less than five minutes.

CHAPTER V

MISCELLANEOUS ITEMS OF A DIVER'S GEAR

Now that we have seen all the important appliances used by the diver, it will be interesting to look at some of the smaller items of his gear before passing on to the work he does as the right-hand of the submarine engineer.

To walk any considerable distance in the boots used by divers would be a physical exercise which I do not recommend to even those in training for big athletic events. They are made of very stout leather, and have "best" leaden soles with brass toe-caps. Their weight ranges from 14 lb. each for shallow water work to 16 lb. and even 18 lb. when intended for use in very deep water. But their clumsiness does not begin and end in their weight alone, the stiffness of the thick leather uppers and the entire absence of "spring" in the soles makes them the most tiring and, in fact, awkward of foot gear. Yet when walking on the sea-bed their weight is scarcely noticeable, and the protection afforded by the metal toe-caps when continually kicking against projections of sharp rock is undeniable.

At first sight it may appear strange that divers should require such heavy soles to their boots, but

a moment's consideration will show that without sufficient weight to counteract that of the heavy helmet and breastplate, combined with the natural tendency to float horizontally, the diver would capsize in the water if, indeed, he succeeded in overcoming the natural buoyancy and were able to sink at all. In the latest pattern Siebe-Gorman diving-dress the legs of the rubber and canvas combination suit are laced at the back (see Fig. 10) with the object of preventing the diver from being capsized and accidentally blown to the surface, or suspended in a helpless position in the water, through the undue inflation of the legs. Should this by no means unlikely mishap occur to a diver wearing the ordinary dress he would capsize with comparative suddenness, and either hang horizontally suspended in the water or float to the surface in a similarly helpless position, in consequence of the air coming down the tube from the surface being unable to escape and consequently blowing out the arms and legs of his dress to such an extent that he would be quite unable to bend any of his limbs. With this new arrangement, which consists simply of lacing tight the

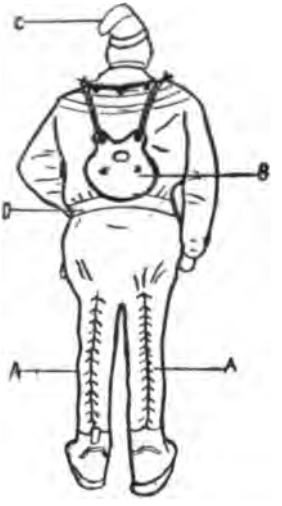

FIG. 10.—Sketch showing diver with the legs of his dress laced tight. *A*. Lacing. *B*. Back weight. *C*. French wood cap. *D*. Waist-belt.

hitherto baggy "pantaloons," in the same manner as an ordinary legging, but little air is allowed to penetrate into this portion of the diver's dress, and consequently, should he be blown to the surface either by accident or design, he would float head upwards, and the air could then be made to escape by opening the outlet valve.

Even with this arrangement, equally as heavy boots are necessary, in addition to the two heart-shaped leaden weights of 40 lb. each worn on the back and front of the breastplate, in order to overcome the natural tendency to float, and to do so horizontally.

Nearly all divers carry a heavy bladed knife with which to cut away obstructions when on the sea-bed. These instruments, which have many times saved the lives of divers attacked by sharks, octopuses, and other denizens of the mysterious under-water world, are usually attached to the waist-belt and worn on the left side. The blade is mostly a very heavy double-edged one, and the metal sheath is much like that of a short bayonet.

Another important item of the diver's equipment is the submarine lamp, for, although during the brightest hours of the day the light of the upper world penetrates into clear watery depths far below those that can be reached by the most experienced diver, it is dim and the hours during which it is possible to see at all grow shorter. The deepest submarine world of which we actually know is, at its clearest and brightest, one of perpetual twi-

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DIVER'S HELMET AND CORSELET, SHOWING INTERIOR MECHANISM

HELMET:

A. Air-inlet valve.
B. Telephone connection for cable.
C. Regulating air-outlet valve.
D. Telephone transmitter.
E. Chin contact for ringing bell.
F. Segmental rings.
G. Telephone receiver.
H. Air deflectors from inlet valve with outlets over glasses.
I. Spit-cock.

light; below lies the unknown of darkness and death.

It is, however, not so much when working in the clear water of the ocean, or in the crystal-like depths of some distant coral sea, that the diver needs a powerful artificial light, but when groping his way about in the darkness which nearly always prevails in the passages and holds of a sunken vessel, and for night use when engaged in salvage operations, laying the concrete blocks of harbours, breakwaters, bridges, and docks, and repairing ships' hulls below the water-line. It then becomes necessary, although in thick muddy water the most powerful lamp is almost useless, the light only tending to increase the fog caused by floating particles.

The many experiments that I have carried out at different times and places with the object of determining the most convenient and at the same time most penetrating form of light for use under water, coupled with the experiences of many others in this field of research, has caused me to come to the conclusion that the electric light is at once the most reliable, suitable, and effective, although oil, with the flame suitably magnified by reflectors and lenses, gives satisfactory results, especially in thick water. It must, however, be remembered that nearly all illuminants need the oxygen in the atmosphere to make them burn properly, and when the supply is cut off the light goes out almost immediately; furthermore, a lamp of this character

being used under water not only needs to be supplied with air from the surface, or from a compressed oxygen cylinder, but must also be provided with a suitable outlet for the products of combustion.

From this it will be seen that the ordinary electric lamp, in which the metal or carbon filament is made to glow in a vacuum, is exceptionally suitable for submarine work, as it requires no oxygen or air-supply and no outlet for fumes.

Electric lamps intended for use under water must possess the following simple qualifications: emit a powerful light and be suitably protected from injury; all joints and connections must be watertight, and all parts be made of a non-corrosive material. Those constructed by Messrs. Siebe, Gorman & Co. are of two different types; one is supplied with electric current by means of wires from the surface, and consists of a group of four incandescent lamps of 50 candle-power each fitted into a strong metal shade with shield. This type of lamp can be either suspended over the work being done or held in the hand, see Fig. 11; while the other pattern, being self-contained, is independent of wires from the surface. It is fitted with dry batteries or accumulators, one charge being sufficient to keep the lamp continuously alight for seven hours. This lamp gives an excellent light, being fitted with single or double bull's-eye lenses, and is used for examining dock walls, ships' bottoms, and propellers, as well as for salvage

operations and work in wells and the flooded galleries of mines.

The air-filter, or baffle, is another important little appliance, as it prevents the air delivered from the pump to the diver from being charged with oil or any foreign matter. It is simplicity itself, consisting merely of a tiny gun-metal chamber made in two halves which screw together; one end connects with the air-pump and the other with the diver's pipe. The air in its passage from the pump to the pipe passes through this small chamber, which is filled with swan's down, loofah, or other filtering material, and is cleansed of all foreign matter such as might be forced out by the action of the pump.

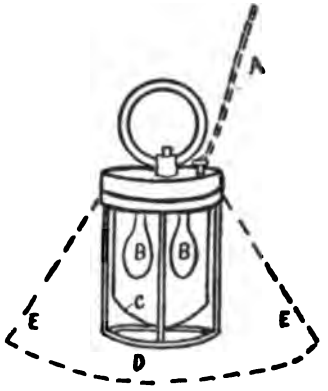

FIG. 11.—Submarine electric lamp, supplied with current from the surface. *A*. Insulated electric cable. *B*. 50 candle-power lamps. *C*. Heavy glass case. *D*. Metal protective frame. *E*. Shade, used when the lamp is suspended over the work being done.

Under ordinary circumstances the hands of a diver are bare, the wristlets of his dress being watertight, but where the water is extremely cold and the hands, if exposed to it, would quickly become numbed, wool-lined gauntlets of vulcanised rubber are worn. By means of metal rings these gloves are made to form a water-tight joint with the cuffs of the diving-dress, and the diver's whole

body is then encased so that, with suitably thick underclothing, he is able without danger or discomfort to work in the coldest water.

There are a few other miscellaneous items of a diver's gear, such as leather knee-pads and chafing leggings for protecting the legs of the diver's dress in cases where the work has perforce to be accomplished in a kneeling position, or where the legs are subjected to an amount of chafing, which might easily cause the dress to become perforated were no additional protection afforded. But we have now seen sufficient of the diver and his dress and of submarine engineering appliances generally to embark on a closer investigation of his difficult and often dangerous work.

CHAPTER VI

DEEP-SEA DIVING

WHEN in an earlier chapter I said something about the pressure of water on a diver's body I purposely omitted giving the pressures at various depths, and the effect of those pressures on the human frame unless certain precautions are taken, in order that the reader might first become acquainted with the appliances in use. It is time now, however, to go "deeper" into the work of the diver, and before this can be done we must know the difficulties and dangers which beset diving in deep water.

DIVING IN DEEP WATER

Assuming that the surface of the body of the average diver is 2160 square inches in superficial area, the total pressure to which he will be exposed at various depths can be easily calculated from the table on following page, which shows the pressure in pounds on the square inch at the depth of water given. The table shows not only the pressure of water at the depths given, but also the time considered safe (British Navy) for the diver to remain under water—from the time he begins to descend from the surface to the time he starts the ascent—and, in the fourth column, the time he *must* occupy in ascending, by stages with frequent halts, from the various depths.

It is important to note that, up to 48 feet, 1 cylinder of a Siebe-Gorman two-cylinder double-acting pump is all that is needed to supply the requisite air to one diver; but 2 cylinders of the same pump are needed from this depth up to 96 feet; and 4 cylinders from thence to 180 feet; and no less than 6 cylinders from 180 feet to the maximum safe depth of 204 feet (*for one diver only*).

Table of Submarine Depths and Pressures.

Depth (in feet).	Pressure (pounds per square inch).	Time under water from surface to beginning of ascent.	Total time which must be taken in ascending.
36	16	No limit.	...
Every 6 ft. to:—			
42	18½	About 3 hours.	6½ minutes.
48	21	,,	12 minutes.
54	24	,,	22 minutes.
60	26½	2 to 3 hours.	32 minutes.
66	29½	1 to 2 hours.	32 minutes.
72	32	1 to 1½ hours.	32 minutes.
78	34½	1 to 1½ hours.	32 minutes.
84	37	40 to 60 minutes.	30 minutes.
90	40	35 to 55 minutes.	32 minutes.
96	42½	30 to 40 minutes.	33 minutes.
Every 12 ft. (expert deep-sea divers only):—			
108	48	25 to 35 minutes.	33 minutes.
120	53½	15 to 30 minutes.	33 minutes.
132	59	12 to 25 minutes.	32 minutes.
144	64½	10 to 20 minutes.	31 minutes.
156	70	10 to 16 minutes.	30 minutes.
168	75	9 to 14 minutes.	30 minutes.
180	80½	Up to 13 minutes.	30 minutes.
192	86	Up to 13 minutes.	32 minutes.
204	91½	Up to 12 minutes.	32 minutes.
(Maximum considered safe.)			

It will be seen from this that a diver working in 32 feet of water will have upon the surface of his whole body a more than ordinary pressure of about 20,000 lb., and that one working at the great depth of 170 feet will have a weight equivalent in pressure to 117,216 lb. on his whole body.

Incredible as it may seem, the human body is

By special permission.

THE DIVERS' HOSPITAL

A decompression chamber into which divers suffering from the effects of a too rapid rise from deep water can be placed and subjected to an air pressure equivalent to that from which they have recently emerged. The decompression takes place very slowly.

able to withstand an even greater pressure than this, for the Spanish diver, Angel Erostarbe, broke into the treasure-room and recovered £9000 in silver bars from the wreck of the steamer *Skyro*, sunk off Cape Finisterre in 182 feet of water; and James Hooper descended to the wreck of the good ship *Cape Horn* off Pichidanque, South America, reaching the astonishing depth of 204 feet! Although this took place some years ago it still constitutes, so far as I am aware, the record submarine dive. At that depth Hooper must have sustained the enormous pressure of 91½ lb. on every square inch of his body.

Deep diving is, however, not common in every form of submarine work, although it is frequently necessary in many different classes of operations. Wreck-raising is seldom attempted when the depth of water at low tide exceeds 100 to 125 feet; the sponge-fishers of the Mediterranean work at a maximum depth of about 150 feet; and the pearl divers of Australia and elsewhere at about 100 to 120 feet; but submarine construction, such as the building of harbours and docks, is seldom conducted in more than 30 to 70 feet of water. In this latter case, however, the divers have to be skilled masons in addition to being experienced divers. It is in the recovery of treasure that diving in very deep water is most frequently undertaken.

The subject of deep-sea diving naturally leads one to think of submarine boats, which it is very generally believed navigate the under-seas at extraordinary depths from the surface. Such is, however, not the case. The submarine seldom descends

lower than 50 feet. The average depth at which submarines of the British and most foreign navies carry out manœuvres is, however, only 15 to 17 feet. Although this is the case now-a-days, several French and American boats experimented in deep diving when this type of craft was in its earliest stages of practical development, and many were the dives of 80, 90, and 100 feet successfully accomplished. But the necessity for the submarine to descend any deeper than 50 feet is seldom likely to obtain in modern warfare. At less than half this depth they are perfectly concealed from the enemy, and can survey the surrounding seas by the aid of their periscopes. At greater depths this instrument is useless, and they must blindly grope their way about; besides, the great object of this type of craft, up to now, is to act as a "daylight torpedo boat," approaching an enemy while concealed below the surface, but sufficiently on a line with the hostile warship's hull to fire a torpedo with reasonable chances of success, and this cannot be done at any but moderate depths.

This is, however, a digression. Returning to the subject of diving in deep water by individual divers, great attention must be paid by the attendants on the surface to the pressure gauge on the pump when a diver is down in deep water. Should the gauge fall quickly (pressure rapidly decrease) it signifies either that the diver is coming to the surface or that something is wrong with the apparatus, and the signal asking if he is "all right" is at once made either by the telephone or the life

line. If the diver is returning to the surface the pump is eased, but should the diver signal back "all right" and the gauge still continue to fall, something is wrong with the apparatus, and he is signalled to come up at once in order that the defect may be repaired. When the gauge rises quickly (pressure rapidly increases) it usually sig-

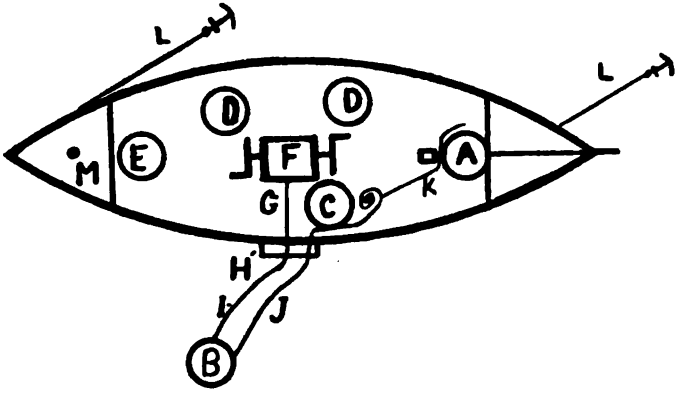

FIG. 12.—Plan of a diving-boat with crew and equipment. *A*. Officer in charge. *B*. Diver working under water. *C*. Attendant holding life-line and air-pipe. *D*. Attendants working the pump. *E*. Spare diver dressed, ready for emergencies. *F*. Pump. *G*. Air-pipe. *H*. Diver's ladder. *I*. Air-pipe to diver. *J*. Life-line containing telephone wire. *K*. Portable telephone exchange and battery. *L*. Anchors. *M*. Mast with red flag.

nifies that the diver has fallen, as the outlet-valve in the helmet will not always act properly if the diver is lying down on the sea-bed. The same signal is made, and if the diver does not reply to it he is hauled up at once, but not too rapidly, as nothing is more dangerous after diving in deep water than to return very quickly to the surface.[1]

[1] The latest practice is to haul the diver up quickly for half the distance and then to intersperse the remainder of the ascent with frequent long halts.

Divers working in over sixty feet of water should be careful not to keep their heads down for more than a few seconds at a time, or the air will accumulate in the dress and cause them to rise quickly; nor should they exert themselves in lifting or pulling, as blood-vessels are easily broken when working under great pressure. A diver never descends into deep water after a heavy meal; and on all occasions when divers are down a red flag is hoisted in the diving boat as a danger signal to passing vessels.

A Diving Party

The instructions given to divers in the British Navy lay down the rule that in all diving operations on wrecks, or where there is danger of a foul, a second diver should be dressed and ready to go down to the assistance of the first should help be required. In the case of vessels having only one set of diving apparatus on board, single-handed diving operations should not be proceeded with if, after careful inspection, there appears to be any danger of the diver being entangled or otherwise becoming in need of a second diver for his safety.

The wisdom of this will quickly be seen when it is pointed out that should the diver's air-pipe become entangled in the debris of a wreck the slightest movement to get free on the part of the diver himself might cause the air-pipe to be severed. Many instances are recorded where the life of one diver has only been saved through the prompt aid given by another, ready dressed for emergencies.

The number of men required for a diving party depends on the number of divers being employed. The following table shows the formation of a party for one or two divers (see Fig. 12):

	Two Divers.	*One Diver.*
In charge	1 officer or sub-engineer.	1 Do.
For life-line and air-pipe	2 experienced attendants.	1 Do.
For pump	2 (not necessarily experienced).	2 Do.
Divers	2 (a spare diver is advisable).	1 Do.

Care of Diving Dress

Great care is taken to prevent the rubber and canvas diving-dresses from being packed away after use in a wet or even damp condition, as they would quickly mildew and become so rotten as to be of little service afterwards. An easy method of drying diving-dresses is to take two pieces of wood, about 8 feet long, nail them together in the form of a St. Andrew's cross, and place them inside each dress, putting another piece through the sleeves to keep them distended. Any number of dresses can then be placed in an upright position until dry, very little floor space being occupied, an important factor when operations are being conducted from a diving boat.

After the day's work is over the joints of the air-pipes are carefully cleaned and the pipes themselves coiled away in the helmet chest. The dresses, after being used in salt water, are washed at least once a week in clean fresh water. Diver's underclothing

should always be kept clean, dry, and aired. Great care must also be exercised to insure the efficient working of the pumps and valves in the diver's helmet.

The Making and Training of Divers

The best school for divers is in the British Royal Navy, although many experts have come both from the American and Japanese fleets, and from the pearl and sponge fisheries; while the warships of almost every maritime power have their complement of experienced divers.

The training of men for diving work is not accomplished in the harsh methods sometimes imagined by people who "have a horror of going under the water." A man once remarked to the author that he supposed beginners were "chucked in with their diving-dresses on and left to get back to the surface as best they could!" He certainly did not realise that learning to dive is not learning to swim, and his benign smile vanished when it was explained to him that such a course would be tantamount to murder!

When choosing men from a ship's company for a course of instruction in submarine diving, they are usually first examined as to their fitness by a medical officer. If this is not possible, however, men of the following types should not be employed for under-water work: (1) those with short necks and full-blooded complexions; (2) sufferers from headache, slight deafness, or those who have had a running from the ear; (3) men who have at any time spat or coughed up blood; (4) those who are subject to palpitation of the heart; (5) men who

have a languid circulation (*i.e.* suffer unduly from cold feet and hands and have pale complexions with lips more blue than red); (6) men who have blood-shot eyes and a high colour on the cheeks caused by numerous small but distinct blood vessels; (7) those who are hard drinkers or have suffered from rheumatism, sunstroke, or other chronic disease.

From this it will be seen that a healthy constitution and what is generally known as a wiry frame are necessary to the would-be diver; but he also needs certain mental qualities, such as coolness in difficulty and danger, boundless resource, pluck, determination, and, above all, confidence in himself and his apparatus. The last of these qualifications, however, only comes with experience.

In the British Navy recruits for the diving classes receive their first practical lessons in large steel tanks erected on dry ground within the precincts of the various dockyards. The depth of the water in these tanks is usually from 12 to 15 feet, and large glass port-holes are provided in the steel sides so that the officer in charge may see that all is well with his "pupils."

After several lessons in these huge tanks, the recruit accompanies experienced divers on several expeditions, and so is gradually accustomed to the use of the diving dress and the various other appliances. In this way he gains confidence, and is soon eager to attempt a descent into the sea itself. Seldom indeed is the young diver hurried into attempting a descent until he has overcome the inherent nervousness occasioned by undertaking a task which has hitherto been unknown to him, but rather is given

time and opportunity to watch others being taught, so that he goes down for the first time feeling that what he has seen others do, perhaps more nervous than himself, he can do also.

At first the embryo diver is allowed to descend on to the sea-bed in shallow water by means of a rope-ladder weighted at the bottom, and is accompanied on these excursions into the submarine world by an experienced hand; but as he gains confidence, first the guide then the rope-ladder is dispensed with, until at last he finds himself quite able to go down unaided by a single rope into comparatively deep water.

Now comes the second stage in the training. Hitherto he has been learning merely to dive, and has descended, moved about on the sea-bed, and returned to the surface without attempting any serious work. All is now changed, however; he is taught what to do in case of accident to himself or to another diver, how to clean a ship's bottom, clear an entangled propeller, free a choked valve, recover a lost anchor or torpedo, lay submarine mines, and, in fact, do the hundred and one things that he will be called upon to do as a qualified diver on one of His Majesty's warships.

When they leave the navy, experienced divers find highly remunerative work on the great submarine construction or salvage works which are constantly being undertaken in all parts of the world, but, although when actually working they may earn anything from £4 to £10 per week, unfortunately there are many, many months in the year when they are out of employment.

CHAPTER VII

THE DIVER ON SHIPBOARD

THE value of the seaman-diver on both the warship and the merchantman cannot well be over-estimated, although thousands of miles of sea are often traversed and weeks pass by during which his services as a diver are, happily, not required. For this reason the diver must make himself useful in other ways, and it is the custom in the British Navy, as well as in the mercantile marine and most foreign navies, for several seamen on each vessel to become qualified in submarine work, for which they receive additional pay and not infrequently an advance in rank. When all is well aboard they perform the ordinary duties of a deck hand, but should an accident happen and repairs to the vessel's hull below the water-line or to the propeller become imperative, they are ready and capable of performing the difficult task.

It sometimes happens that a steamer is ploughing her way across the open sea, hundreds of miles from a harbour, when she is suddenly brought to a standstill and rendered almost helpless by the entangling of her propellers in floating wreckage. It is at a moment like this when the value of a diver becomes apparent. A boat is lowered or a

temporary stage rigged over the stern, and the the diver descends from this on to the submerged propellers. Here, with the aid of a few tools, such as a wire-rope cutter, he is mostly able, in a comparatively short space of time, to clear away the obstruction and enable the vessel to proceed on her way. Again, should a vessel strike waterlogged wreckage, or a rock in fog or darkness, the extent of the damage can quickly be ascertained, and possibly the foundering of the vessel averted, by the prompt action of several qualified divers.

The cleaning of the submerged portion of the ships' hulls is, however, one of the principal tasks of the seaman-diver. Since the use of iron and copper in the construction of vessels the fouling of their hulls below the water-line from seaweed, barnacles, and incrustations generally has become a serious matter, owing to the loss of speed entailed on long voyages. The various anti-fouling compositions now being used to reduce these incrustations to a minimum have done something towards easing the work of the diver in this direction, but even now his services cannot be dispensed with unless the vessel is continually being docked for the purpose of being cleaned and put in a proper state to proceed to sea.

Take the case of the Baltic Fleet on its voyage to the Far East during the Russo-Japanese War. The hulls of many of these warships became so foul that the speed of the entire fleet was reduced by several knots an hour. What this reduction in

speed means in loss of time on a voyage of many thousand miles is easily understood. A vessel which on leaving dock has a maximum speed of, say, 15 knots per hour, will, under the most favourable circumstances, scarcely be able to do 12 knots per hour after seven or eight months at sea, unless her bottom is cleaned in the meanwhile.

In the early days of the iron ship the trouble experienced with corrosion was far greater than it is to-day. When the *Great Eastern* returned from laying the Atlantic cable, incrustations were found to the thickness of one foot! The hull of this large vessel was then thoroughly cleaned by six divers in one month, and Captain Halpin reported that after this had been done the gain in speed exceeded two knots per hour.

Cleaning the bottom of a large ship while afloat is by no means a simple task, and the *modus operandi* is best described with the aid of diagrams.

A glance at Fig. 13 will show that a broad rope-ladder, with wood or iron rounds, called the "keel-ladder," is first passed completely under the vessel and secured on both sides. To prevent this ladder from getting so close against the vessel's hull that no foothold is afforded, buffers of wood or rope (*A*) are fastened on the ends of each rung or round. The ladder is drawn tight so that these buffers rest against the sides of the vessel, and so hold the ladder rigid at a short distance from the plating.

When the diver descends from a small boat on to the keel-ladder, he takes with him under wate

a "hanging stage" (*B*), to be used as a seat when the work of cleaning commences. This can be hooked on to any rung of the ladder, and moved forward as the work proceeds.

The actual scrubbing and scraping of the hull may be done with four different implements, ac-

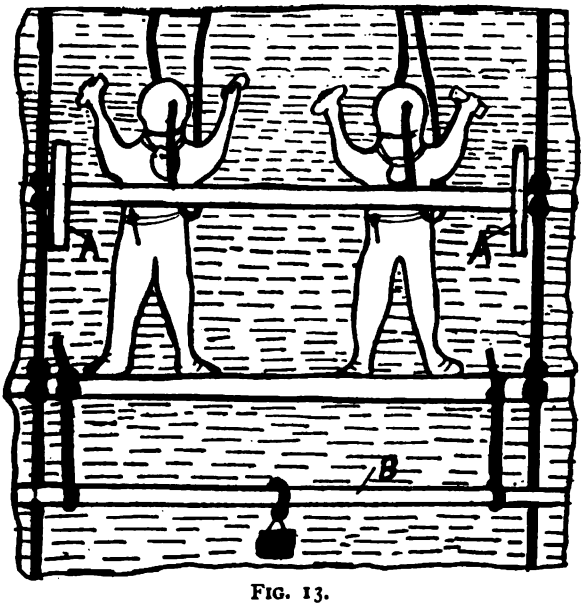

FIG. 13.

cording to the state of foulness of the ship's bottom. A couch-grass brush is often used to clean the ordinary plating on which there is only slime and seaweed, but when barnacles and thick incrustation are encountered a brush made of brass-wire or an iron scraper must be used to remove the small shells and other very adhesive bodies.

The diver moves his swinging seat from rung to

rung along the ladder, cleaning the plating on each side as far as his arms can reach. Eventually he passes completely under the vessel and comes to the surface on the opposite side. When the whole bottom of a vessel is being cleaned the keel-ladder has to be continually moved forward or backward as the case may be. After each move the diver cleans a further section; thus, in a vessel 300 feet

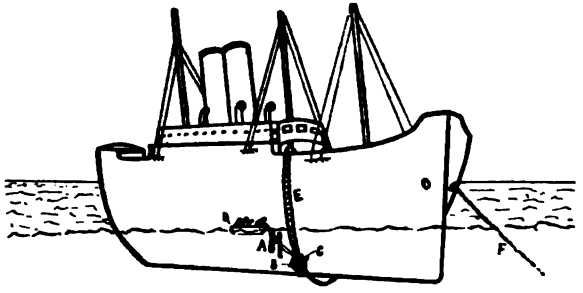

FIG. 14.—Sketch showing method of cleaning submerged portion of a vessel's hull. *A*. Diving ladder. *B*. Slung seat. *C*. Diver at work. *D*. Diving boat. *E*. Keel-ladder. *F*. Anchor chain.

long, the sections to be cleaned would probably number about seventy-five, each section being about 4 feet wide.

It is generally estimated that an experienced diver can work from four to seven hours daily below the hull of a vessel, and can clean from five to ten square yards per hour, according to the condition of the plating. This, however, does not refer to cases where the incrustation is above the normal.

Another arrangement, known as the Admiralty

pattern staging, has been found very useful in cleaning and re-coppering the bottoms of vessels. Its construction is simple, and will be easily understood from the diagram (Fig. 13). When working on the vertical portions of the ship's hull the divers stand on the lower spar, with their backs resting against the top one, but when operating on other portions of the bottom they sit on the slung spar.

This simple arrangement not only enables two divers to work simultaneously on one section of the hull, but also allows them wider scope, as they can, with perfect ease and safety, move backwards and forwards along the twenty-foot spars.

Recovering Lost Anchors and Torpedoes

Among other tasks which the seaman-diver is often called upon to perform is the recovery of lost anchors and torpedoes. The former task is an easy one compared with the latter, as the position of a *slipped* or lost anchor is mostly known, and it only remains for the diver to descend and either loosen it or simply fix on a chain and shackle, with which it can be hoisted from its bed by powerful winches. The case of a lost torpedo is, however, different. After being fired from the tube it has probably turned "eccentric" (*i.e.* deviated from the straight line) and then sunk, its whereabouts remaining a mystery. An organised search over, perhaps, a square mile of sea has then to be under-

taken, and continual descents and explorations by divers have often to be made before the truant torpedo is discovered.

Repairing Damage

When a collision occurs at sea and one of the vessels is damaged below the water-line, it sometimes becomes necessary for divers to be slung over the side for the purpose of more securely fastening the "collision-mats" over the gap in the vessel's hull. The roll of the vessel, the suction of the water, and the necessity for haste make the fixing of these heavy and cumbersome waterproof mats a task of considerable difficulty and danger.

It would be almost impossible to mention the many and often curious tasks which the seaman-diver is called upon to perform. Contingencies arise at sea which often have few precedents, and much therefore depends upon the ingenuity and daring of the diver. Most of the divers engaged on the great submarine construction works and important salvage cases have spent many years at sea, more often than not in the Navy.

CHAPTER VIII

THE INVENTIONS AND EXPLOITS OF HENRY FLEUSS

HENRY FLEUSS, a native of Wiltshire, commenced the invention of his now famous diving and respiratory apparatus in 1876, while serving at sea as an officer in the Mercantile Marine. With practically no data to go upon he had to essay many dangerous experiments and to overcome many difficulties, studying at the same time the physiological aspects of the problem he had set himself to overcome.

In 1879, without ever having donned a diving-dress before, he tried his then cumbersome apparatus in the tank at the Old Polytechnic in Regent Street, and remained under water for about one hour at the first attempt. He afterwards gave public exhibitions of his apparatus at this and other institutions, often remaining under water for two or three hours at a time.

It was then suggested to him that an apparatus for entering the galleries of mines filled with noxious gases would be useful, and in the early part of 1880 he produced the very first respiratory apparatus for this purpose. Its essential features

were practically identical with all similar apparatus of to-day though it was much more cumbersome, as in those days it was very difficult to obtain compressed oxygen.

At first Fleuss made all his own oxygen, and invented the apparatus for compressing it to about 800 or 1000 lb. per square inch.

This compressor is worth mentioning here, for though slow and somewhat complicated it was very reliable. He employed a hydraulic ram pump to which was attached a strong wrought-iron cylinder filled with suitable stop-cocks and a union for attaching to the vessel to be charged with gas under pressure.

The pump was made to deliver water into the wrought-iron cylinder, the exact capacity of which was marked off in the water tank of the pump.

The oxygen used was made from chlorate of potash, washed and delivered into the well-known rubber bags of that period which were attached by a rubber tube to one of the upper cocks of the iron cylinder. The cylinder was then filled with water to drive out all atmospheric air, and the water afterwards run off and its place occupied by oxygen from the bag; water being again pumped into the iron cylinder until it was exactly full drove all that charge of oxygen into the upper chamber, the stop valve of which was then closed and the operation was repeated until the desired pressure and quantity of gas in the receiver was obtained.

About this time Fleuss discovered that oxygen

was being made and sold compressed to about 600 lb. per square inch by a Mr. Orchard in Kensington, but the cylinders in which the gas was stored were too heavy and cumbersome to be carried by a man as part of the respiratory apparatus. It was also difficult in those days to obtain a fairly quick-acting portable air-compressor to more than 300 lb. per square inch, so Fleuss had to arrange the size of his container to the pressures then most readily obtainable, hence it was somewhat crude and cumbersome.

The first apparatus he designed for diving work had a large stiffened rubber mask covering mouth, nose, and eyes, and in order to give it a thorough test Fleuss went into the water with it, at Wootten Creek, Isle of Wight, bareheaded and without any waterproof diving-dress; sinking was accomplished by tying pieces of iron and lead to his belt and winding pieces of chain about his ankles; the water was about 18 feet deep, and at first he went in without a life line attached, but on the persuasion of friends and onlookers he allowed them to attach a small life and signalling line, the other end of which was held in a boat being rowed slowly about up and down the creek.

Fleuss had hitherto allowed himself to be guided by text-books, from which he gathered that the breathing of a large excess of oxygen would produce injurious effects, such as excitability or feverish rise of temperature, and he therefore took the trouble to partly inflate the collapsible breathing-

bag with atmospheric air before finally adjusting the face mask, and then admitted oxygen as required to keep about the same degree of inflation. With his many experiments in producing an efficient absorber for carbonic acid gas he well knew the unpleasant effects of too much of this gas, but he had never tried the effects of an excess of nitrogen, so while quietly strolling down the bed of the creek it occurred to him to shut off his oxygen supply entirely, just to see what the symptoms would be when more oxygen was required; as is well known now, insensibility occurred quite suddenly.

His friends in the boat on the surface noticing that he was very still, and getting no answer to the life-line signals, pulled him up and hauled him into the boat apparently dead. He explained afterwards to the writer that his first sensation when regaining consciousness was a great pain in the chest, that he seemed to be in a kind of nightmare, and that men were throwing lumps of rock and smashing in his ribs. The men in the boat say that they had great difficulty in holding him down, and that he tried to jump overboard again. Suddenly he sat up and vomited a considerable quantity of blood, after which the pain ceased and he became quite sensible, though very weak. Medical examination showed that only half of one lung was left in a breathable condition, all the remainder being torn and saturated with blood. The explanation of this mishap is that Fleuss had

become insensible under a pressure equivalent to the 18 feet of water in which he was at the time, whereas when respiration recommenced he was under just so much less pressure, which, coming suddenly upon the lung tissues, simply burst them.

A few weeks after this mishap Fleuss felt himself well enough to try again, but this time he put the apparatus on without any inflation of atmospheric air, and he found that with oxygen which is free from nitrogen it is impossible for such a mishap to occur. Since then he has frequently shut off his oxygen supply until the breathing-bag was so flat that it would only supply two or three cubic inches for inspiration, and that these two or three cubic inches of comparatively pure oxygen will perfectly well support life, so that should the oxygen supply in the modern apparatus be neglected, a long period of warning is given by the gradual diminution of the volume available for each inspiration. He also discovered the important fact that pure oxygen can be breathed with impunity and, in fact, great comfort, for periods well beyond all working requirements, and also under some pressure, though medical authorities disagree with Fleuss as to the pressures under which oxygen can be breathed with safety.

Oxygen is now largely made from atmospheric air, and is liable to contain traces of nitrogen, which might bring about an unsafe percentage of nitrogen in the breathing-bag when the apparatus has been worn for a considerable time. To obviate

all risks of this character the supply of oxygen to the breathing bag is now made continuous, and is governed by a reducing valve which is set to deliver constantly the maximum quantity that a

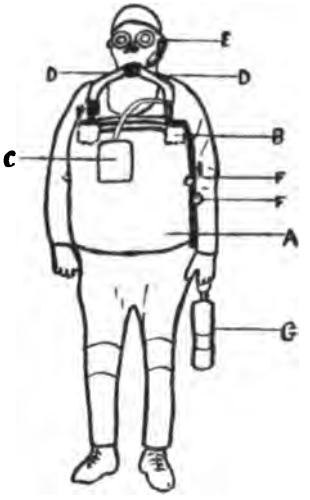

FIG. 15.—Sketch showing principal features of the Fleuss respiratory apparatus. Although largely used for rescue work in mines, it can also be employed as a shallow-water diving-dress. *A*. Canvas bag inflated with pure air from cylinders carried on the back (see Fig. 16). *B*. Pipes conveying air to mouthpiece. *C*. Caustic soda chamber for absorbing the carbonic acid of respired air. *D*. Face mask. *E*. Goggles. *F*. Small wheels for regulating the air supply. *G*. Submarine or miner's lamp.

man would require when doing a maximum amount of work, and which he would only be capable of doing for short periods.

This causes the breathing bag to become over-inflated from time to time, but the excess of oxygen is very readily made to escape either by opening

the relief valve on the bag itself, or by forcing the head-piece slightly away from the face, which instantly allows the excess gas to escape. In this way the bag is, so to speak, washed out from time to time, and no dangerous accumulation of nitrogen can possibly occur.

It was at this time that the Severn Tunnel, which was then in course of construction, became flooded, and it was found necessary to send a diver a distance of 1020 feet up one of the headings to close an iron door and some sluice valves. Many attempts were made by the celebrated diver, Alexander Lambert, who, however, found it quite impossible to drag his air-pipe and life-line along such a distance; and in the early part of November 1880 Fleuss volunteered to make the attempt with his apparatus, which was at least independent of an air-pipe. He had spent all his available money upon this invention, and could not even afford to take with him a trained assistant who understood his apparatus, so he went alone, trusting to find any stranger upon the works to attend to him and his signal line.

He arrived in the small hours of the morning, and after a short rest was ready to meet the contractor, who showed him the plans of the flooded heading and gave him some very brief information regarding the dangers to be met with in the perilous task he was about to undertake. At first the diver, Lambert, was in no good temper, and rather scoffed at Fleuss and his apparatus, but he

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FOR RESCUE WORK IN POISONOUS ATMOSPHERES

A man equipped in this oxygen-breathing apparatus (Fleuss, Davis and Hill's Patents) has accomplished over 350,000 foot-pounds of work in two hours. For rescue work in mines it is invaluable.

was soon talked into a better mood. Fleuss having had no experience of work under water or in such absolute darkness as prevailed in the flooded subterranean galleries, begged Lambert to go down to the bottom of the shaft and stand at the entrance to the heading ready to assist him in taking off his

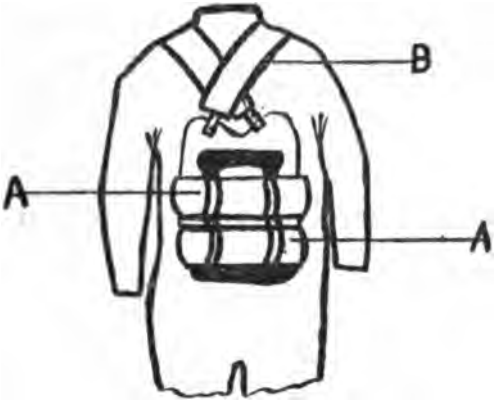

FIG. 16.—Back view of Fleuss respiratory apparatus.
A. Cylinders containing compressed air or oxygen.
B. Straps supporting same.

life-line, for it was quite useless to attempt to drag the line after him.

The shaft was about 200 feet deep, and the water stood 40 feet in depth at the bottom. Just above the surface was a platform with a small hatchway, or manhole, and vertical ladders, joined end to end, reached from the top of the shaft down through the hatchway into the water. A man was told off to be Fleuss's assistant in dressing, putting on weights, helmet, &c., and Fleuss there and then explained

his duties, which were quite different from those of an ordinary diver's attendant.

After going down the ladder to the platform and having his boots, with 16 lb. of lead on each, strapped to his feet, he sat upon the edge of the manhole while his front and back weights, life-line, and helmet were adjusted, and then commenced the descent. Lambert in an ordinary diving-dress had already gone down and was waiting for him somewhere in the darkness below. No one had told him that the ladder did not reach the bottom by some 10 or 12 feet, and when he reached the last rung and hung upon it with his hands, he guessed that he could not be far off, and so let go.

The darkness was absolute, and he stood still for an instant to consider which way to move, then walked forward to feel for the wall of the shaft. Several times as he stepped he felt planks giving way under him. It was only a partly broken-up platform over a 7 feet pump—none had told him of this either. Working his way round the wall of the shaft, he came presently to an opening, and, stepping across this with outstretched arm, found Lambert waiting for him. They shook hands, and then, as pre-arranged, he motioned Lambert to unfasten his life-line.

When this was done Fleuss started to make his way up the heading, guiding himself as best he could by the tramway metals which ran along the centre.

There was some danger in getting off the track,

as a ditch had been constructed on either side of the heading, and the sleepers of odd lengths projected over it, making a terrible fall possible with every step. Feeling the tram metals with a 16 lb. leaden sole was very difficult for an untrained man, and he then tried crawling on hands and knees. Even this way was no easy task, as there were falls from the roof in several places.

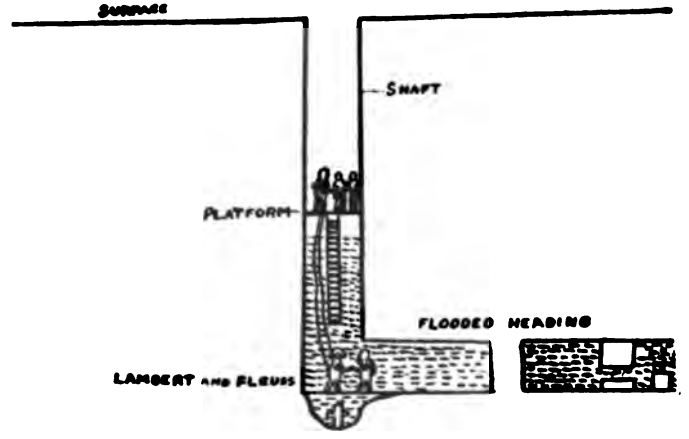

FIG. 17.—Sketch showing Fleuss and Lambert in the flooded heading of the Severn Tunnel.

After being down about an hour and a half, and knowing that his progress had been very slow, Fleuss thought he would return and make another attempt later on, feeling that he would be able to get along more quickly as he got gradually more accustomed to the strange surroundings. He had no difficulty in finding Lambert and motioning him to refasten the life-line, and when giving the usual signal for coming up he doubted whether his

untrained attendant would give him the necessary assistance to reach the short ladder, but all went well, and he succeeded in mounting to the surface.

From the description given of the wreckage, Lambert told Fleuss that he had been about 100 yards up the flooded heading, and he thereupon decided to descend again the same afternoon, taking with him a crowbar with which to more rapidly feel the way along the tramway metals.

At the second attempt Fleuss succeeded in getting further up the heading than he had done on the previous occasion, but he still felt that his progress was much too slow for him to be able to reach the sluice valves and effect a safe return. With the same want of complete success he made a third and fourth attempt, each time gaining experience and getting a little nearer the goal.

Lambert began to look more favourably on the apparatus than he had done at first, and told Fleuss that if he understood the use of it he was sure he could reach the valve and carry out the necessary work.

Fleuss at once agreed to his trying, explained the apparatus, and assisted him in practising with it at the bottom of the shaft.

Lambert, being an expert diver, soon gained sufficient confidence to enable him to make the attempt. He had to go 1020 feet up the heading, creep through a brick tunnel 4 feet in diameter and 9 feet in length, remove the tram metals and sleepers which prevented a strong iron door

from closing, and to screw down a 12 inch sluice valve.

Lambert was away exactly an hour and a half at his first attempt, and when he returned to the surface he explained that he had removed the greater part of the obstructions which prevented the closing of the iron door, but was unable to complete the work owing to the crowbar he carried being too long.

Again he entered the flooded heading, and this time succeeded in closing the door. The enormous volume of water which was being continually pumped out caused a strong current to flow through the narrow brick tunnel, and when once the iron door started to swing it came to with great force, shaking the timbers supporting the roof of the heading, and causing Lambert to fear that some part of the roof might have fallen and blocked his return.

Although much damage was done by the vibration, Lambert succeeded in getting out, and the Severn Tunnel was cleared of water.

CHAPTER IX

THE PIPELESS DIVING-DRESS

THE last chapter deals mainly with the remarkable inventions and exploits of Henry Fleuss. We now come to the more recent adaptation of the respiratory apparatus for general submarine work. It is known as the "Pipeless," or self-contained diving-dress, and is the result of the collective ingenuity of Messrs. Fleuss, Davis, and Hill—three gentlemen whose scientific attainments have long been devoted to the submarine branch of engineering science.

The pipeless diving-dress has been designed more particularly for work in flooded mines and other places where it would be quite impossible for the diver to drag behind him a long air-pipe. The case of the flooded heading in the Severn Tunnel, described in the last chapter, was a concrete illustration of the difficulties to be overcome in this class of submarine work. Even in open sea operations there are occasions when the self-contained dress proves of great assistance, owing to the complete freedom of movement which it allows the diver. Its use at present is, however, limited to short periods at moderate depths, the duration of the air-supply with each "charge" being

about two hours, and the maximum depth of water in which it is considered safe to work about fifty feet. In this dress the diver carries with him under water all the pure air he will require, and consequently, with the exception of the life-line

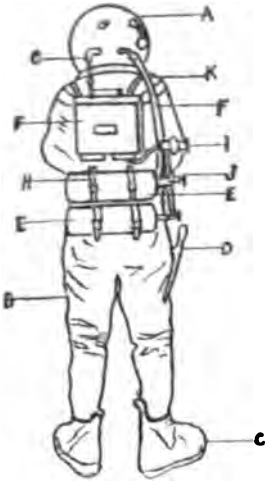

FIG. 18.—Sketch showing the pipeless or self-contained diving-dress. *A*. Helmet. *B*. Ordinary diving-dress. *C*. Weighted boots. *D*. Diver's knife. *E*. Cylinders of compressed air. *F*. Pipe supplying air to helmet. *G*. Pipe leading to air-purifying chamber. *H*. Straps supporting air-cylinders. *I*. Valve regulating air-supply. *J*. Ditto. *K*. Shoulder-straps supporting apparatus.

containing the telephone wire, he is quite independent of the surface.

The ordinary helmet and diving dress is used in combination with two small steel cylinders slung on the back. Into these is compressed a large quantity of air mixed with an extra proportion of oxygen. Above the cylinders is a small metal

chamber containing caustic soda, which absorbs the carbonic acid produced by breathing. Both the cylinders and the metal chamber are connected with the helmet by pipes and valves. By this means the air in the helmet can be breathed several times over, owing to the purifying effects of the caustic soda, and at the same time slowly replaced by fresh air let in from the cylinders. A careful study of the illustration on page 97 will make this clear.

This, however, is not all, for a safety device is attached whereby, in the event of anything going wrong with one or more of the valves regulating the air-supply between the cylinders and the helmet, the diver is able to obtain the requisite amount for breathing independent of the valves, and any excess of air that accumulates in the dress escapes automatically.

With this dress the ordinary weighted boots are required to make the diver sink, and also the lead weight worn on the breastplate, but the usual back weight is dispensed with, as the steel cylinders and caustic soda chamber are, in themselves, heavy enough to compensate for its loss.

The complete freedom of action which this dress allows a diver when moving about under water is, of course, its most useful feature. When clambering over obstacles or making way up the flooded heading of a mine, the absence of the "drag" of an air-pipe not only makes the actual task much more easy of accomplishment, but also considerably

reduces the risk of accident. With an air-pipe behind him, which grows more difficult to drag with every yard of progress made from the base, the diver is never sure that some sharp projection may not sever the hose, or falling debris flatten it, and so cut off his air-supply almost before he is aware of it. Again, should the pipe only become entangled, the diver may experience great difficulty in freeing himself in the pall-like darkness of a flooded mine or ship's gangway.

Even the self-contained dress has its disadvantages, however, for the time under water is at present strictly limited to two hours. This necessitates the diver taking great care that he does not get such a distance away from the base, or so entangled, that his air-supply is exhausted before he is able to extricate himself and return to the surface. In the case of an experienced diver, however, these possibilities are so remote that they need scarcely be considered.

This brings us to the question of recharging the small air-cylinders after they have been used. In order to do this a large storage cylinder containing 100 cubic feet of oxygen and air, compressed to about 120 atmospheres and capable of recharging many sets of apparatus, is kept in readiness on the surface, together with a supply of caustic soda for recharging the chamber in which the respired air is purified.

CHAPTER X

HOW SALVAGE OPERATIONS ARE CONDUCTED

IT is doubtful whether there is any branch of marine engineering so fascinating, so precarious, and so wide in its scope for the exercise of engineering skill and ingenuity, combined with seamanship, as wreck-raising.

In these days of "Dreadnought" battleships and gigantic ocean liners, when the sinking of a single vessel, even in comparatively shallow water, may mean the loss of a million sterling, the importance of salvage work will be fully realised. Apart, however, from warships and ocean greyhounds, the number of vessels of all types and sizes which run ashore or founder through fogs, gales, collisions, or other causes is now so considerable that enormous financial losses would continually be suffered by the shipping and marine insurance communities were it not for the submarine engineer and his numerous appliances for wreck-raising and the salving of sunken specie and cargo. Yet withal there are occasions when even he is powerless, for an example of which it is only necessary to recall the loss of the

Titanic, which unfortunate vessel foundered in such a depth of water (1¾ miles) that operations for her recovery were quite impossible; but, on the other hand, the foundering of vessels in mid-ocean is of much less frequent occurrence than it is in the narrow and crowded waterways, where collision is the chief source of danger, or around treacherous coasts, where rocks and shoals are a far greater menace to shipping than are gales on the high seas.

A reliable estimate places the value of vessels and cargo lost around the British Isles alone at over £9,000,000 per annum.

Although salvage operations may be divided into three distinct classes—the raising of wrecks, the salving of cargo, and the recovery of specie—the methods employed vary so considerably that I shall deal with the first two separately, devoting a succeeding chapter to the hazardous work of treasure salving.

In the raising of wrecks and their cargo, much depends upon the depth of water, the position in which the wreck is lying, and the condition of the hull. The first step is therefore to locate the sunken vessel, and if the depth of water does not exceed that which is considered safe for divers—130 to 180 feet—the work of raising is possible of accomplishment, although when the depth of water is more than about 100 feet, and the wreck lies in an exposed position or tideway, the task is likely

to prove a difficult one. In the case of vessels sunk so deep that the use of pumping machinery would be ineffectual, the salvor must resort to "lifting-vessels" or large pontoons moored over the wreck; but in anything like shallow water centrifugal pumps and coffer-dams are the most reliable appliances.

The essential feature before any work can be commenced is fair weather, for during gales, or even with choppy seas, no salvage operations can be undertaken with safety. When the wreck lies in an exposed position it is often necessary, during certain periods of the year, to wait several weeks before any continuance of calm can be relied upon.

The first step in all salvage operations is to send down divers to locate and examine the vessel, and to carefully ascertain the extent of the damage. On their collective reports the engineer-captain in command bases his plan of operations.

Let us first assume that the work is that of a large cargo steamer of 5000 tons displacement, which struck a rock during a fog and slid off again, foundering in 50 feet of water—a disaster almost identical to many which occur every year. The reports of the divers state that she lies 40 feet deep at the bow and 31 feet at the stern, with a list to starboard of 15 degrees. The damage to her hull is fairly extensive, several plates being ripped open, and the starboard bow completely crushed in by the impact with the rock. The tops of her masts project above the surface, but even at low

tide her decks are covered by about 18 feet of water.

These are the main factors in the problem to be solved, but there are several questions which must be answered before a plan of operations can be decided upon. The nearest harbour into which the wreck can be towed when raised is forty miles distant. Her cargo consists of boxes of fruit, and the character of the surrounding sea-bed and coast-line is decidedly rocky.

The importance of these points will be better realised when it is pointed out that had a harbour been but a mile or two distant, and the floor of the sea smooth and sandy, with a gentle incline towards the shore, it might have been possible to raise the wreck a few feet with each tide by means of steel hawsers suspended from lifting-craft on the surface (see Fig. 21), and then to tow her slowly towards the shore until she rested again on the bottom, continuing this operation with each tide until the harbour was reached, and the wreck placed in dry-dock. But, apart from the distance of the harbour and the rocky sea-bed, which would make such an operation quite impossible, the size of the vessel tells strongly against this method.

Before the actual raising of the vessel can be commenced, the cargo must be removed in order to lighten the wreck as much as possible. For this reason its nature is an important factor. Had it been a "loose" cargo, such as coal, the time, danger and difficulty of unloading the vessel under

water would have been more than doubled; but, on the other hand, if it had been oil, which is easily pumped out, the large tanks specially fitted into the vessel for its storage would have proved of inestimable value in the work of raising, as they could have been quickly converted into watertight compartments, and the buoyancy thus attained would have greatly assisted in the raising of the vessel.

In this case, however, the position of the wreck is decidedly awkward, but the cargo is one which can be easily removed by divers, and although the damage to the hull is fairly extensive it is decided to attempt to repair this and free the vessel of water by means of the powerful centrifugal pumps installed on the salvage vessel.

Divers are sent down to open the hatches and clear the holds, which is done by attaching ropes to the boxes of fruit and hoisting them to the surface. When this is accomplished the huge rent in the bow of the vessel is temporarily repaired and made water-tight by means of bricks and a special kind of cement which has the properties of setting quickly in water and adhering to iron. This "wall," stopping the water from flowing through the hole made in the vessel's hull, is supported internally by metal girders, and a timber shield is placed over the outside to insure that no water will re-enter once the interior is pumped dry. A projection of rock, which had penetrated through the bottom when the vessel sank, is care-

fully blasted away by small dynamite cartridges, and the aperture filled by a "leak-stopper" (see Fig. 19). This consists of a kind of T-headed bolt; the cross-piece (*A*), being on a swivel, can be closed to insert it through the hole, and then opened to afford a secure purchase. A washer-plate, (*B*) to cover the leak, can then be slipped on to the screwed-spindle, (*C*) and secured over the hole by a tightly screwed-up nut. The washer consists of a metal plate faced with layers of thick felt (*D*) which when pressed tightly against the side of a ship embeds any jagged edges or irregularities of the rent, thus forming a thoroughly watertight patch.

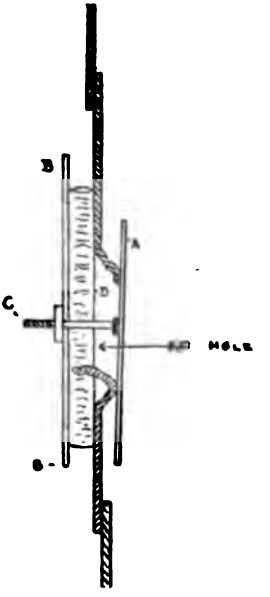

FIG. 19.—Leak-stopper.

The hatches in the deck, and all other openings, except those specially prepared for the entry, through watertight joints, of the suction-pipes, are then securely battened down—thus the whole hull of the vessel is made watertight. The pipes from three 12-inch "Invincible" centrifugal pumping engines are then introduced into the various holds, and the water pumped out in a combined stream equal to over 2520 *tons* per hour.

Pumping at this speed, which is by no means abnormal for such work, the sunken vessel is

cleared of water and made to rise to the surface by her own buoyancy in a few hours. Tugs then tow her into dry-dock, where the damage to her hull can be permanently repaired.

Seldom indeed is it, however, that the work of salving a sunken vessel proceeds so smoothly. The s.s. *Hypatia* of Christiania was four times actually brought to the surface, and through the failure of some portion of the raising apparatus each time she sank back into the sea, but was finally recovered on the fifth attempt.

Another method of salving a sunken vessel, even more frequently employed than the one just described, is by means of a "coffer-dam." The *modus operandi* is to extend the vessel's hull upwards from the deck to the water-level with the aid of planks and cross timbers.

This is one of those occasions when a few simple diagrams will more easily explain the appliance than several pages of description.

A number of beams are first attached to the gunwales in an upright position, boarding is then placed between them and the interstices filled up with cement. By this means a huge watertight box is formed which reaches from the submerged vessel's deck to the surface. The damage to the hull is then repaired, and the water pumped out of the coffer-dam. It will be seen that the leaks are "patched" and the whole centre of the vessel is enclosed in this temporary compartment. The water is then pumped out of the space enclosed by

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A COFFER-DAM

The timbers are holding back deep water while a dock wall is being built (H.M. Dockyard, Portsmouth).

the coffer-dam, and the vessel made to rise to the surface.

This method is undoubtedly the most reliable, as

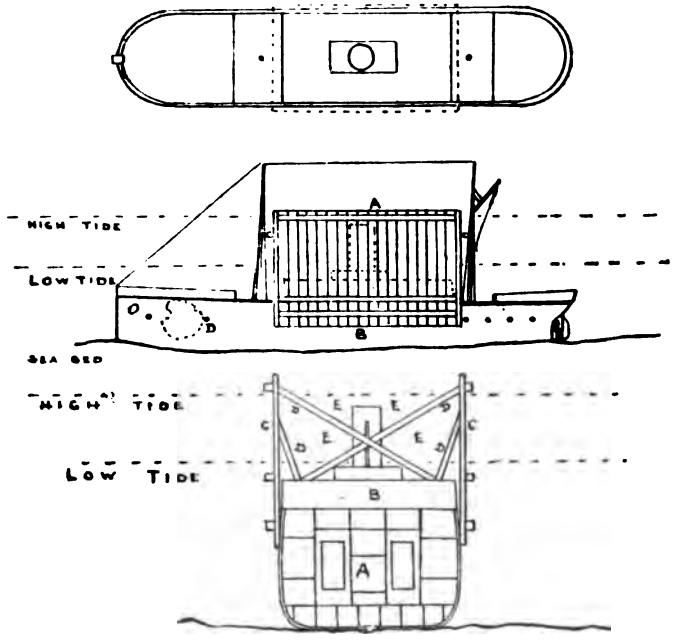

FIG. 20.—Wrecked steamer being raised by "coffer-dam." (1) Plan of vessel. Dotted lines indicate usual position of coffer-dam, *i.e.* enclosing whole centre of vessel. (2) Elevation, showing timbers of coffer-dam. *A*. Top projecting a few feet above high-water level. *B*. Bottom securely fixed to gunwales and made watertight. *D*. Repair to damaged hull. (3) Cross-section. *A*. Boiler-room bulkhead. *B*. Upper, or boat-deck. *C*. Sides of coffer-dam. *D*. Cross-timbers supporting "walls." *E*. Space enclosed by coffer-dam from which water is sucked by centrifugal pumps.

not only is the major portion of the wreck encased in a kind of outer skin which, extending from the gunwales to the surface, makes every point water-tight, but no such strain is placed on the deck as in

the method first described. It will be apparent that where the leak or damage to the wreck is repaired and the water pumped out in order to make the vessel rise by its own buoyancy, the weight (or pressure) of water on the deck is enormous, and it not infrequently happens that this gives way under the strain, and so not only destroys all the work done, but also makes further efforts scarcely worth

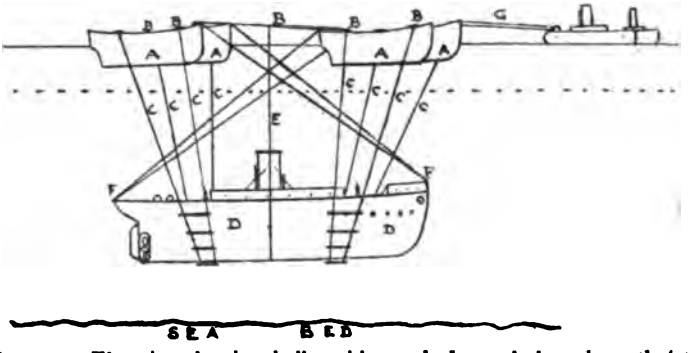

FIG. 21.—Elevation showing hulks with wrecked vessel slung beneath (at high tide) being towed into shallower water. *A*. Hulks. *B*. Cross-timbers. *C*. Flexible wire hausers. *D*. Timbers forming kind of cradle. *E*. Wire-rope support. *F*. Guiding ropes. *G*. Towing hawsers.

while owing to the terribly damaged condition of the wreck.[1]

The coffer-dam is mostly employed where the depth of water does not exceed 40 to 50 feet, and on occasions when the deck of the wrecked vessel shows above the surface at low tide, which is often the case where a vessel has run on the rocks inshore during a fog, or gets stranded on a sand-bank.

[1] The exact pressure of water on the hull of a sunken vessel, when the interior is clear of water, can be estimated from the table of water-pressures at various depths given on p. 68.

How Salvage Operations are Conducted

Where the water is very deep and there is a considerable rise and fall of the tide, "lifting craft" are usually resorted to. Two or more large hulks, held securely together by beams, and having a combined buoyancy sufficient not only to sustain the dead-weight to be raised, but also to allow a safe margin, are moored over the wreck in the manner shown in Fig. 21.

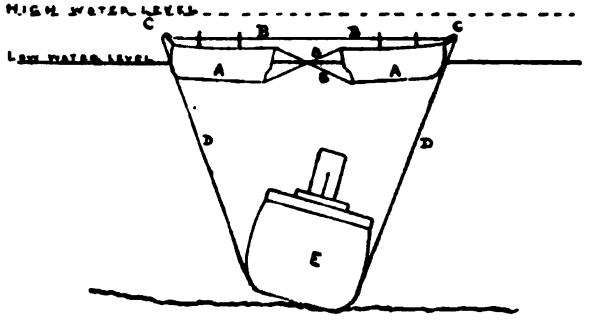

FIG. 22.—Section showing hulks *A* moored over wreck *E*. *B*. Cross-timbers holding hulks in position. *C*. Sheaves. *D*. Flexible wire hawsers.

Divers then descend and pass 7 or 9-inch flexible wire hawsers completely under the wrecked vessel, both ends of the hawsers being carried up over sheaves to the lifting-hulks, forming slings which are drawn taut when the tide is at its lowest point. As the tide rises the wreck is lifted off the bottom, and the hulks supporting it are towed slowly into more shallow water. This operation is repeated with each tide until the wreck is either deposited safely in dry-dock or left high and dry on some protected strand (see Fig. 22).

This method is used with equal possibilities of success—in salvage work most things are possible, but nothing certain—for raising both fairly large and small vessels. The ill-fated British naval submarine "A1" was carried into Portsmouth harbour from its temporary grave off the Isle of Wight slung beneath two lighters, while the s.s. *Locksley Hall*, of 2000 tons dead-weight, sunk in the Mersey, was raised in this way by four hulks each capable of lifting over 500 tons.

In places where there is no appreciable rise and fall of tide, and owing to the damaged condition of the wreck, the depth of water, or other cause, salvage pumping machinery could not be used successfully, the method usually employed is to sling the wreck, by means of stout wire hawsers, to hulks moored on the surface, in the same way as previously described, but in this case water is then pumped into the hulks in order to sink them as deep as possible consistent with safety, and the wire hawsers drawn taut by powerful steam-winches. Iron or wooden pontoons—huge rectangular caissons—with a combined buoyancy of about 700 to 1000 tons, according to the weight to be raised, are then sunk by having water let into them and attached to the sides of the wreck. They are connected by pipes to the compressed-air reservoir on the salvage ship. A reference to Fig. 23 will make this clear.

When all is in position, the water is pumped out of the hulks and simultaneously expelled from the

pontoons by compressed-air. By this means, if the lifting power exerted by the natural buoyancy of the pontoons and hulks has been carefully calculated—as all calculations must be in submarine engineering—the wreck is lifted off the sea-bed and can be towed into shallow water.

A notable instance of wreck-raising by this means

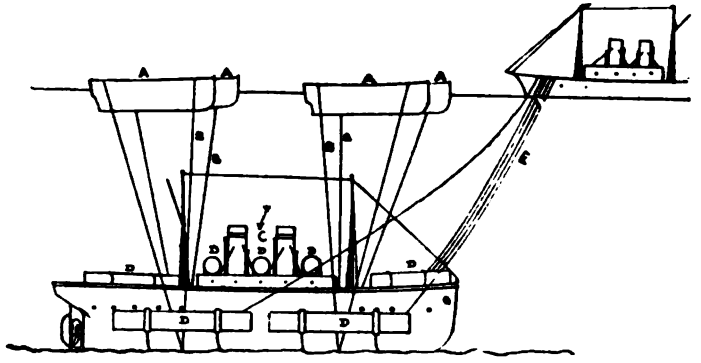

FIG. 23.—Elevation showing disposition of pontoons to insure the vessel rising evenly. *A*. Hulks. *B*. Steel-wire hawsers. *C*. Wrecked vessel. *D*. Pontoons. *E*. Air-pipes from the various pontoons leading up to salvage ship.

occurred in Queen Charlotte Sound, New Zealand, where the s.s. *Taranaki* was recovered from a depth of over 105 feet!

Salving by means of pontoons is, however, fraught with many difficulties. Should a cable break with the enormous strain, or the pontoons not rise evenly, the preparatory work may suddenly be undone. This will be seen from what happened during the raising of a dredger which had capsized and gone down in the river Elbe. Pontoons had

been sunk into position and gigantic trestles erected to act as levers in righting the vessel when lifted from the river-bed. After many difficulties had been overcome, the dredger rose to the surface keel uppermost, and was in the act of being righted when the trestles suddenly collapsed simultaneously

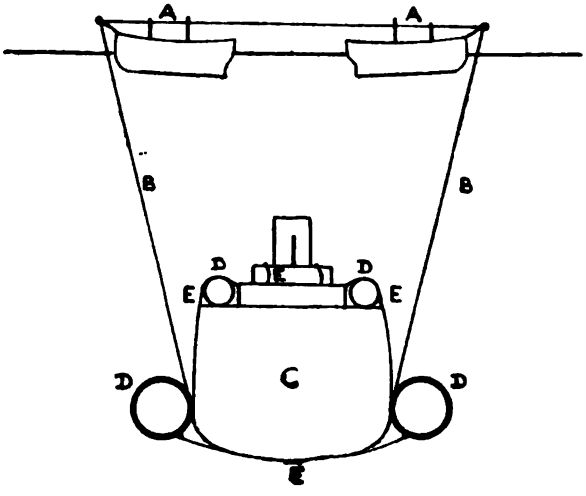

FIG. 24.—Cross-section showing disposition of pontoons. *A*. Hulks. *B*. Wire hawsers. *C*. Wreck. *D*. Pontoons. *E*. Wire ropes and metal bands holding pontoons in position.

with many of the hawsers owing to some abnormal strain which had not been accounted for, and the dredger rolled over and sank back on to the river-bed, destroying in a moment the difficult and dangerous work of many weeks.[1]

Where quite small vessels have to be dealt with, a capital plan is to place a number of watertight

[1] The refractory dredger was finally recovered after many weeks' work.

barrels and rubber bags in the vessel's hold and then expel the water from the former and inflate the latter with air forced down through connecting tubes by small compressors on the surface. Care must, however, be taken to regulate the supply of air so as not to burst the receptacles.

Another situation which salvage engineers have occasionally to face is that of a vessel stranded high and dry on the shore. It is by no means an uncommon circumstance during very heavy gales for a vessel to be caught up by a wave and stranded upon the coast. In the China Sea, where cyclones are of frequent occurrence, a vessel is sometimes carried inland on the "back" of a tidal wave for over a mile, and, when the waters have subsided, is left high and dry, perhaps 2000, or even 3000, yards from her native element.

Invariably the vessel sustains but little damage, and the salvage engineer immediately sets to work to restore her to the sea. A wooden slipway is sometimes constructed, along which the vessel is hauled on well-greased rollers; but where the distance to the water is only short, as is mostly the case when a vessel runs ashore during a gale and is left stranded on a sandy beach, a more general method is to open a temporary canal, wide and deep enough to allow the vessel to float down it when filled with water by the flowing tide.

A vessel stranded in this way on a rock-strewn coast would, in all probability, become a total wreck and not worth the trouble and expense of

refloating; but, where the shore is low lying and sandy, great difficulty is experienced in preventing the work accomplished at low water from being obliterated by the incoming tide. To prevent this the banks of the temporary canal are frequently lined with sacks filled with sand and held in place by rows of stakes.

It is often necessary when salving a large vessel to amputate a "limb" or portion of the hull in order to save the most valuable section. A remarkable accomplishment of this kind, which illustrates the method usually employed, was the salvage of a portion of the s.s. *Milwaukee*, a vessel of 7300 tons displacement, which ran on the rocks near Aberdeen while on a voyage from the Tyne to New Orleans. Although the water was shallow, the vessel was so securely jammed on the rocks and her fore-part so extensively damaged, that Captain Bachelor, superintending the work for the Liverpool Salvage Association, decided that it was only possible to save the after-part, containing the machinery and boilers. A belt of dynamite cartridges was placed round the hull, at a point just in front of the engine-room. Great care had to be taken that the explosions did not damage the bulkhead, and the actual work of cutting the vessel in halves occupied several days, 500 lb. of dynamite being used in the operation.

This difficult task was, however, successfully accomplished, and the after-section of the vessel floated off the rocks. But a new danger now

arose; the weight of the engines and boilers caused one end of the floating section to sink so deep that much anxiety was felt as to whether the boiler-room bulkhead would stand the pressure of water, but, fortunately for the success of the undertaking, it withstood the great strain, and the most valuable portion of the *Milwaukee* was towed back to the Tyne, a distance of 160 miles, helping the tugs as far as possible with her own engines.

CHAPTER XI

SOME REMARKABLE SALVAGE FEATS

DURING a blizzard on April 25, 1908, a disastrous collision occurred in the Solent between H.M. cruiser *Gladiator* and the American liner *St. Paul.* The force of the impact was so great that the *Gladiator*, which was struck by the passenger steamer a sliding blow abaft the boiler space on the starboard side, had about 50 feet of plating, including framing, deck-beams, and bunker-casing carried away, the consequence being that the boiler-rooms were immediately flooded. So serious was the situation that promptness in beaching the war-ship alone averted a catastrophe. She took the ground on a shelving beach, and was left stranded by the tide lying on her starboard side, with her deck, which was facing the shore, at an angle of 93 degrees, and only the port side remaining above water at high tide. The divers found that although she rested on sand and shingle, forming a smooth, hard bed, it was very necessary that no time should be lost in getting her more inshore, as the beach shelved quickly, and there was great danger of her slipping back into deep water.

The first thing to be done was to relieve the hull of all superfluous weight, but the difficulties of

this operation were greatly enhanced by the strong ebb tide which set across the bow, forming eddies. This will be better realised when it is stated that the tide ran at the rate of eight knots an hour at springs (highest tides), and limited the time available for diving operations very considerably. However, by the aid of pneumatic tools, the casings were cut away, and the funnels, guns, shields, ventilators, davits, and other fittings of a varied description were successfully salved.

The damaged portion of the hull had turned over on the port side as the vessel heeled, and this torn section was removed by means of explosives. Where openings existed, wooden covers were fitted and made watertight. When these preparations were completed, the vessel was ready to be hauled into more shallow water.

The system employed in raising the *Gladiator* will be more readily understood by referring to Figs. 25 and 26. Two circular pontoons (*A* and *B*), each 50 feet long and 10 feet in diameter, constructed of steel plates and fitted with water-admission valves for sinking purposes, as well as valves, connected by pipes with air-compressors, for expelling the water when refloating, were secured to the starboard side; this was accomplished by fixing steel bollards on the port side, which was above water. The circumference of the pontoons had external channel stiffeners (*C*) 10 inches deep, which were utilised for wire ropes connecting them with the wreck. A 9-inch cable passed from the

pontoons completely under the *Gladiator*, and was then made fast to the bollards on the port side. On the water being pumped from the pontoons, the force exerted by the buoyancy of the pontoons was directed in such a way that the vessel was

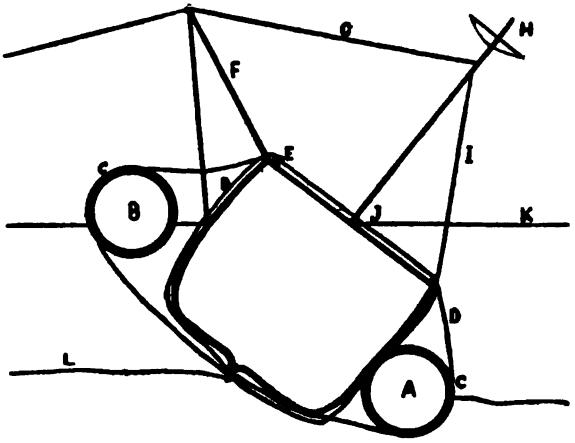

FIG. 25.—Section sketch, showing method of righting H.M.S. *Gladiator*. *A* and *B*. Pontoons. *C*. Channel-iron stiffeners carrying ropes. *D*. Wire rope of sunken starboard pontoon. *E*. Bollard to which pontoon *A* was fixed. *F*. Tripod. *G*. Rope from mast-head passing over tripod to steam capstan. *H*. Ship's mast. *I*. Stay. *J*. Deck. *K*. Level of water surface. *L*. Sea-bed.

pulled into a more upright position, thus rendering it easier to haul her inshore.

Five river gunboats, each carrying centrifugal pumps and having specially strong moorings in view of the strength of the tide, were placed bow on to the wreck, and tugs were in attendance. It was, however, not possible for the tugs alone to exert a sufficiently strong and steady pull, so heavy steam capstans were fitted up on shore. The bow

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THE SALVAGE OF THE S.S. "FLESWICK"

Raised from the sea-bed by compressed air and righted by powerful capstans.

hawse-pipes of the wreck were utilised to receive the chain cables, which were connected by 8-inch wire ropes to the capstans. (See Fig. 26.)

Pumping operations were now carried on apace, but at this stage it was found impracticable, owing to the great damage amidships, to pump out the two flooded boiler-rooms. The pumping, had, however, resulted in a 10 degrees

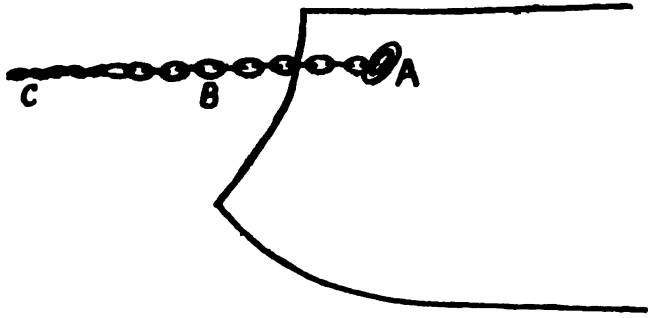

FIG. 26.—Bow of warship. *A*. Hawse-pipe. *B*. Chain cables. *C*. 8-inch wire ropes to capstans.

alteration of the vessel's heel, and she was, at the same time, being held up in a great measure by the pontoons.

By the united effort of the tugs and capstans on shore, the vessel was now moved a distance of about 6 feet shorewards, further progress being stopped by the foreward bridge, which projected beyond the ship's bulwark, becoming embedded in the beach. When this bridge had been removed, the work was resumed, and the capstans and tugs then succeeded in drawing the vessel another 30 feet in towards the shore. This was considered

sufficient for the work of getting her upright to be commenced.

It may be mentioned here that in all seven steel circular pontoons were brought into use; two have already been described, and the dimensions of the remaining five were as follows: two, 30 feet by 13 feet; two, 40 feet by 12 feet; and one, 75 feet by 12 feet. All but two of these were placed on the starboard side, the largest being adjacent to the damage; the two remaining acted as a counterpoise on the port side to prevent any possibility of the vessel heeling over in that direction after she had been brought to an upright position.

Two heavy tripods had, in the meantime, been erected on the port side opposite to each mast. At the top of each tripod a heavy casting, taking a 6-inch wire rope, was fitted, one end of the rope leading to a salvage steamer and the other end to the masthead of the wreck. The two salvage steamers were situated some 300 feet seawards of the *Gladiator*, and were securely moored to 7-ton stern anchors. The wire ropes were first led through large leading-blocks on the bows of the salvage ships, back along the decks to 50-ton purchases. Powerful winches then wound in the ropes, utilising the tripods as a fulcrum and exerting a strong pull on the masts.

Pig iron weighing 250 tons was placed on the port bilge keel and assisted in righting the vessel. To prevent any possibility of the vessel slipping back into deep water, 6-inch wire ropes were taken from the mastheads to the shore, and then secured

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THE SALVING OF H.M.S. "GLADIATOR"

This view shows the vessel refloated, with two of the huge pontoons alongside.

to purchases worked from the capstans, so that they could be made taut or let out as required.

The next step was to place the pontoons in certain positions, and they were then partly sunk. The two salvage ships were in readiness with their leverage appliances, and the river gunboats carrying the centrifugal pumps were brought close alongside the wreck. To obtain the very best results from the pumps, the steamers were moored directly over the pontoons. On commencing operations, 6000 tons of water were pumped from the forward and aft compartments and from No. 1 boiler-room and the engine-room. Directly the pumps had made headway the salvage craft were moved back in readiness to commence hauling. The pontoons were then cleared of water by compressed air—at a pressure of about 20 lb. to the square inch—and, with the assistance of their acquired buoyancy, combined with the pull exerted by the salvage steamers on the ropes leading from the *Gladiator's* mastheads through the tripods, the wreck was brought into an upright position.

The complete salvage of the warship was, however, not yet accomplished. Owing to the small rise and fall of the tides, coupled with the inconsiderable freeboard of the vessel, only the port side was above water, the starboard side being still immersed to the depth of several feet. It was therefore decided to construct a coffer-dam which should enclose the after section of the upper deck, and smaller separate ones over the engine and boiler spaces. It will thus be seen that the starboard

side was completely walled up, making it possible for the centrifugal pumps to be transferred from the attendant ships to the boat-deck of the wreck, and the water to be quickly pumped out from the spaces enclosed by the coffer-dams.

When the final effort in this difficult and complicated salvage operation was made, the whole of the pumps were set to work simultaneously, and with a salvage steamer on each side, the pontoons in position, and the pumps working at full pressure to keep the various compartments free from water, the *Gladiator* was refloated and safely towed into Portsmouth Dockyard.

The attempted recovery of the wrecked *Grosser Kurfurst*, a German warship—although occurring over thirty years ago, and never really completed owing to financial difficulties—was an extremely difficult problem which was practically solved, and is therefore of special interest.

The warship had been sunk in a collision with another German craft just off Dover, and was discovered by the divers to be lying in the extraordinary position of *keel uppermost*, but a careful examination revealed the fact that the ship was holed in one place only, viz. below the armour plating on the port quarter.

It was decided to construct an iron shield with a rim on which was riveted a hollow channel iron. A strong india-rubber hosepipe capable of resisting a very high pressure was fitted into this channel,

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THE SALVAGE OF THE S.S. "FLESWICK"

A view taken at low tide showing the vessel after the last lift.

and when the shield had been securely fastened over the torn plating of the vessel's side, water was pumped into this hose—much as a bicycle tyre is inflated with air—and a complete watertight cover was thus formed, as no water could penetrate between the shield and the skin of the vessel (see Fig. 27). Wire cables were then stretched along the whole length of the vessel's keel, and were securely fastened with chains at the bow and stern. Stays from her portholes on either side crossed the fore and aft cables, already mentioned, at every 10 feet, and were securely fastened where they crossed. Sunken flexible pontoons were designed to be fixed at these points, with a total lifting power of 1000 tons. These pontoons were intended to steady the vessel and prevent her turning over. In the meantime the vessel herself was to be pumped sufficiently full of air to cause her to float, and then to be towed to a safer and more convenient place and turned upright.

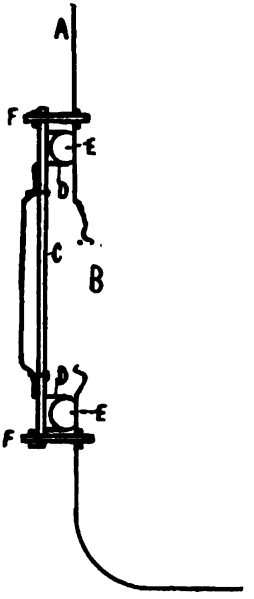

FIG. 27.—Iron shield. *A*. Sides of vessel. *B*. Torn and holed plates. *C*. Iron shield. *D*. Channels. *E*. Inflated india-rubber hosepipe. *F*. Bolts holding shield to sides of ship.

This interesting salvage operation was, unfortunately, never completed owing to lack of funds.

Some Remarkable Salvage Feats

The *Fleswick* was laden with coals when she sank through a collision in Cork Harbour. She lay on her right side across a strong tideway with her bow in about 26 feet of water and her stern in nearly 40 feet. Messrs. Ensor & Son, of Queenstown, who undertook the work of salvage, decided to try compressed air for lifting and righting her. The total under-water weight to be raised being nearly 600 tons.

The two hatchways and the ventilators opening into the holds were securely stopped up, and the engine and boiler space down to the casing, and the after-peak and cabins were also closed. Compressed air was then forced in to replace the water, for which outlets were provided. The lifting power obtained amounted to 400 tons from the holds, 60 tons from the engine space, and 40 tons from the after-peak and cabin. Owing, however, to the small amount of air space available in the after part of the vessel, it was found necessary to use a lifting-hulk with wire hawsers to assist in raising the stern. When air had been pumped in at the rate of about 400 cubic feet per minute, a steady shoreward pull on the wreck was maintained by heavy hauling plant rigged up on shore, and the vessel slid forward over the mud until she was allowed to rest in quite shallow water.

The use of compressed air not only reduced the risk of breaking the vessel in two where she had been damaged by the collision—as would almost surely have resulted had she been slung beneath

lifting-hulks—but also avoided the great damage to the bulwarks and deck structures usually caused when hawsers are employed.

Although but a small task as modern ship salvage goes, the raising of the *Fleswick* afforded excellent proof of what can be done under favourable circumstances with compressed air alone.

CHAPTER XII

THE DIVING-BELL AND AIR-LOCK

THE perfection of the modern diving-dress has done much to supplant that ancient apparatus the "diving-bell," which, however, is still used, not only for the preparatory levelling of the sea-bed, but also for laying the immense concrete blocks which form the submarine foundations of most large breakwaters, docks, and bridges.

The conception of this apparatus—usually assigned to the sixteenth century—was probably due to a simple experiment with which we are all familiar, that of placing an inverted tumbler in a tank of water and observing that the water is prevented from filling the tumbler by the compressed air inside it. The pressure of water, however, increases with the depth, as has already been explained in a previous chapter, and consequently the air-space in an inverted receptacle like a tumbler would gradually get smaller the deeper the vessel was sunk below the surface. Thus, if a diving-bell were submerged to, say, 40 feet, the pressure of water would exceed 17 pounds to the square inch, and the air inside would be compressed to about half its original volume, while the water would have mounted about half-way up

the inside of the bell. This process would continue the deeper the bell was sunk, and the air-space be reduced accordingly.

Dr. Edmund Halley used a crude apparatus of this kind early in the eighteenth century. It was 3 feet broad at the top, 5 feet at the bottom, and 8 feet in height. The whole bell was covered with lead, and weights were also disposed round the lower edge so as to insure its sinking in a perpendicular direction. In the top were fixed several pieces of strong glass to admit light, and likewise a valve and small pump to eject the air corrupted by breathing. Around the inner circumference of the bell a seat was placed for the divers. The whole machine was suspended by ropes from a cross-beam made fast to the mast of a ship. That the bell might be supplied with fresh air to replace the foul ejected by the pump in the roof, large vessels filled with compressed air were lowered by ropes from the surface and their contents released into the bell. Dr. Halley and four other persons remained in this clumsy apparatus at a depth of ten fathoms for an hour and a half without suffering the slightest injury.

Dr. Halley also invented a leaden cap, fashioned like a small bell and connected with the larger one by an air-pipe, which, on being donned so as to cover the diver's head and shoulders, enabled him to leave the large bell when on the sea-bed.

The modern diving-bell is, however, a much more perfect apparatus, although it still retains its

original characteristics, the principal improvement being that the water is never allowed to rise more than a few inches up the inside; air at a pressure equal to that of the water at the depth to which the bell is submerged is forced down through a connecting tube by compressors on the surface. By this means not only is the water kept down to the bottom, or cutting-edge of the bell, but a continuous supply of fresh air is insured, the foul being allowed to escape, and the occupants are thus enabled to continue work on the sea-bed for many hours at a stretch.

Let us take a seat and descend to the sea-bed inside one of the largest and most modern of these bells—such a one as was employed in the construction of the naval harbour at Dover. The steel interior measures 17 feet long by 10 feet 6 inches wide, and no difficulty is experienced even by a tall man in standing perfectly upright. Seats, which can be removed when work is commenced, and foot-rails are provided, and the cumbersome system of ballast tanks used in the older types is entirely dispensed with, consequently there is much more room inside. The divers, about four in number, enter the bell and seat themselves along the sides, then the "Titan" crane begins to lift the huge steel structure, which is swung on massive chains, and lower it down towards the surface of the sea.

Seated in the bell, one looks down through the yawning mouth at the slowly nearing water, wonder-

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THE SALVING OF THE S.S. "MONTGOMERY"

This illustration shows the steamship cut in two for the purpose of salving the valuable stern section containing the engines. A new bow was fitted when the severed section had been recovered and towed into dry-dock. This difficult operation was successfully carried out by the East Coast Salvage Co.

ing how it will feel when, with a splash, its edges touch the surface and the small steel room disappears beneath the sea. But time for reflection is short, the sea suddenly appears to come up and almost touch one's feet, then with a slight splash

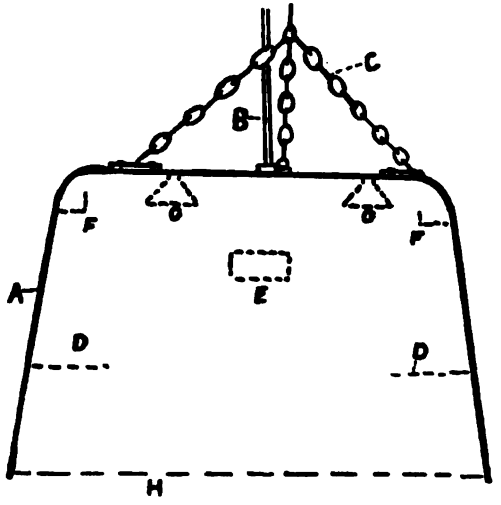


FIG. 28.—Section of a diving-bell. *A*. Steel sides of bell. *B*. Pipe conveying compressed air from the surface. *C*. Chains supporting bell. *D*. Seats for divers which can be folded up when work commences. *E*. Submarine telephone box. *F*. Rack for tools. *G*. Electric lamps. *H*. Cutting-edge of bell.

the water closes round, and a moment later the sunlight which has been streaming through the lenses, or portholes in the top of the bell, disappears, and the interior grows dim. This is, however, only momentary, for scarcely has twilight grown to semi-darkness before the whole interior is flooded by the rays of numerous electric lamps, and a low

hissing noise somewhere in the roof proclaims that compressed air is being forced down the tube from the surface.

The swaying, sinking motion which has been experienced since the bell entered the water gradually ceases, and presently there is a slight noise as the cutting-edge rests on the sea-bed. The bell is again hoisted a few feet and swung forward until it is suspended over the rocks which require levelling, in order that the foundations of a concrete wall may be securely laid. A telephone bell now rings, and the "captain" of the shift immediately speaks into the mouthpiece fixed to the steel side.

"Is it the 'crane' ringing up?" asks some one whose voice sounds hollow and loud in the intense silence of the ocean.

"No, it's the 'compressor'; he wants to know if we are getting enough air!" replies the captain, glancing at the water lapping a few inches up the inside of the bell, and then turning again to shout into the receiver, "Well, we could do with a little more, it (the water) might be a bit lower—eh?—what's that you say?—we are down forty feet and the pressure is seventeen pounds per square inch? All right, give us a quarter of a pound more and don't be mingy with the air, it isn't yours!"

All now becomes life and activity. The divers, who, by the way, are called divers only by virtue of their occupation, as no helmet or special dress is required in a bell, now commence operations with

the tools which have been resting on shelves fixed to the steel walls. The shallow water becomes thick and chalky as the work of levelling the sea-bed proceeds apace, and ever and anon one of the divers climbs up on the footrail, dripping wet to the waist, either to fetch down some new tool from the shelves or to take a "pull" of cold tea from a bottle.

Hours pass by and still the work proceeds, until at last a rock, more stubborn that the rest, resists all efforts to move it, and a telephonic message is sent to the surface asking for the assistance of the pneumatic drills fitted into the bell. The necessary supply of compressed air, which is forced down a pipe separate from the one continually supplying the bell, is soon forthcoming, and the work continues with the aid of rock-drills and hammers operated by air at a pressure of about 100 lb. to the square inch.

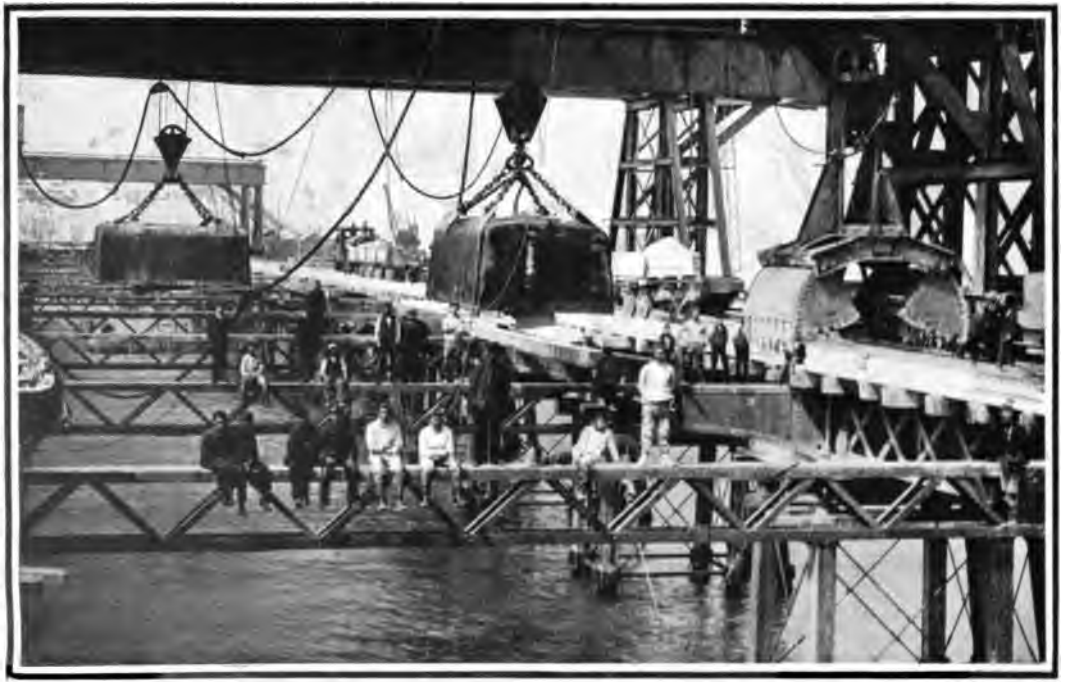
Breathing compressed air is not dangerous providing that the pressure is not suddenly removed, but when first experienced it is by no means pleasant. A throbbing in the head, sometimes accompanied by pain in the ears and giddiness are the usual symptoms, which, however, may easily be overcome by taking shorter breaths and repeatedly swallowing saliva until accustomed to the pressure. Many people imagine that work under water, whether it be in a submarine boat, bell, or diving-dress, is invariably accompanied by a sense of suffocation caused by want of air. This is not

exactly the case, although a novice often experiences a feeling of suffocation, which is, however, frequently produced not by want of sufficient air, although nervousness will increase the amount required, but by having too much, or breathing it under pressure. But these horrors are more in the imagination than in the reality.

The refractory rock has at last been levelled with the aid of the pneumatic drills and hammers, and as a change of crew is now necessary the heavy steel bell is hauled slowly to the surface.

The ascent sometimes produces a remarkable phenomenon inside the bell. The air, being relieved of pressure, quickly expands and drops in temperature. The moisture held is condensed and a vapour or slight mistiness becomes visible; but a quite modern appliance which cools, dries, and purifies the air before it is delivered to the bell has done much to obviate this unpleasantness when rising to the surface. The same phenomenon, in a more marked degree, is produced by suddenly releasing air compressed in a cylinder.

Before passing on to examine the auxiliary surface machinery, there is another type of diving-bell which must first be described. This is the "air-lock bell," frequently used in the construction of large bridges. The illustration facing page 150 and Fig. 35 show the interior arrangement of this type of bell, and from these it will be seen that a tube leads up from the roof of the working chamber to the surface. The important characteristic of



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DIVING-BELLS AT THE DOVER NAVAL HARBOUR WORKS

General view of one section of the works, showing two of the diving-bells, each measuring 17 feet long by 10 feet broad and 6 feet 6 inches high; and weighing about 35 tons.

this type of bell is the "air-lock," through which divers may enter or leave the bell when under water. The mouth is open, and compressed air is supplied to keep out the water, as in the ordinary bell; but a tube, several feet in diameter, up and down which divers can climb, projects from the roof of the bell to the surface. The air-lock is a chamber above the bell itself. If a diver needs to leave the bell he mounts into this chamber, closing an air-tight door behind him, and allows the compressed air in the "lock" to slowly escape up the shaft until it is at the ordinary atmospheric pressure, when he is free to leave the air-lock and mount to the surface.

If, on the other hand, a person desires to enter the diving-bell he descends from the surface into this chamber, and after closing an air-tight door behind him, turns on the compressed air supply and waits until the pressure is equal to, or slightly in excess of, what it is in the bell itself, when he may continue the descent to the working chamber without any fear of the water entering. This system of maintaining the pressure of air in the bell while divers are entering and leaving is of considerable utility where submarine works of great magnitude are being constructed in fairly still water, as, for instance, in excavating on river-beds for the reception of pier piles or bridge cylinders.

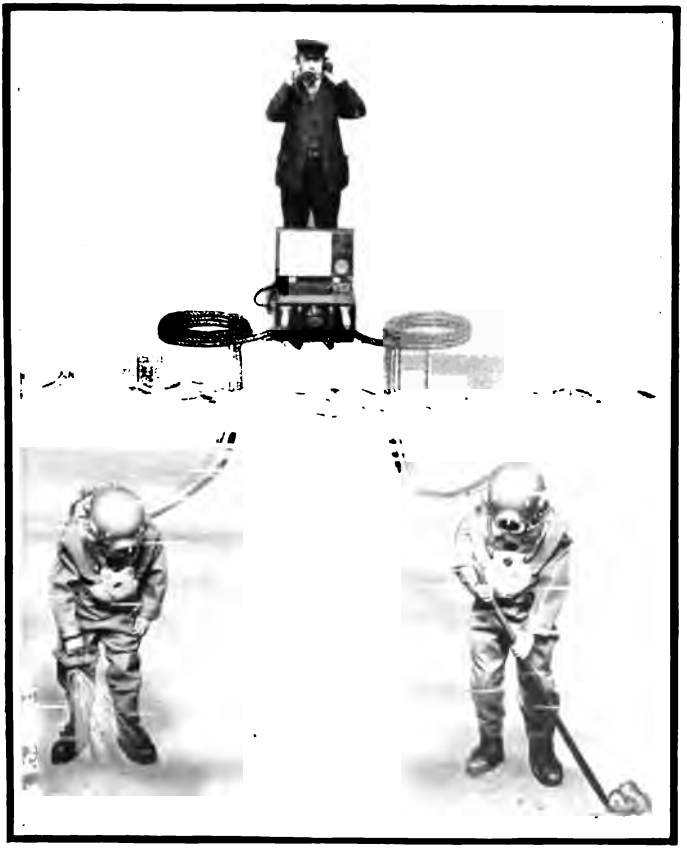
On some works of this kind air-locks are used in conjunction with the cylinders forming the supports of the bridge or pier. In a case where it is

desired to sink the cylinder deep into the river-bed, in order to give it a solid foundation, an air-lock is fixed to the surface-end and compressed air let into the cylinder until the water is forced out. By this means the cylinder actually becomes the diving-bell, and men may enter it through the air-lock at the top, descend by steps inside, and excavate the river-bed until the cylinder has sunk sufficiently deep of its own accord.[1]

In these appliances men are subjected to a greater pressure of air than in any other apparatus used in engineering work. Some years ago it was generally believed that men could not be safely employed in these cylinders at a depth of more than 65 feet, where the pressure of air necessary to hold back the water exceeds 30 lb. to the square inch, but as far back as 1855 the central pier of the Saltash Bridge was sunk to a total depth of nearly 88 feet below high-water level, and in more recent years the foundations of the St. Louis Bridge over the Mississippi have been placed at a depth of 110 feet, where the pressure reached 50 lb. to the square inch. The question of man's ability to live under high pressure of air has, however, been fully dealt with in a previous chapter.

Let us now examine the complicated surface machinery, fixed on the temporary pier beside the "Titan" crane which lowered the bell into the depths of the sea, for it is these marvels of modern

[1] This system is employed mostly in the construction of bridges supported by enormous iron caissons.



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THE SUBMARINE TELEPHONE

This drawing shows the working of the submarine telephone. The attendant on the surface is answering the call of one diver who is asking to be put in communication with the other.

mechanism which have been supplying us with such an abundance of pure air and electric light during our four hours' submergence.

The first to claim our attention is the pair of double-acting, steam-driven air-compressors, working so smoothly in a little shed raised high above the tides on the piles of the temporary pier. These compressors work tandem fashion, on one bed-plate, and are so arranged that one or both can be worked at the same time, according to the depth of water in which the bell is being used, because, as we have pointed out previously, the force of air required depends entirely upon the pressure of water at the mouth of the bell, and the resistance of the connecting pipe consequent on the depth of water in which the work is being conducted. These compressors are driven by a steam-engine of 45 horse-power.

There is yet another important appliance connected with the delivery of air to the diving-bell. This is the intermediary "air-receiver," a large tank made of steel plates, subjected to the test of a pressure of 150 lb. to the square inch. In this case the receiver—as it is required not only to supply the air to the diving-bell and divers working independently, but also for the pneumatic tools, and is, in fact, the reservoir supplying the breath of life to the whole army of under-water workers engaged on this portion of the great harbour works—is a vessel as large as it is important. It is 20 feet in length, 5 feet in diameter, and holds 392 cubic

feet of highly-compressed air, which is forced into it by the steam-driven compressor. It is fitted with the usual safety-valve and blow-off cock, which operate immediately the supply of air exceeds the demand, and a gauge shows the pressure of air being forced in by the compressor. Numerous flexible pipes lead away from it into the maze of surface and under-water workings.

These reservoirs are used in order to insure a steady working pressure and supply of air to the bells, divers, and pneumatic tools dependent upon it for life and energy. If the air were delivered direct from the compressing-engine, it would not be nearly so regular, and a momentary stoppage would instantly cut off the supply; but with this reservoir as a kind of intermediary storage-battery, not only is the supply under more exact control, but ample time is allowed, should the compressor come to grief, for the bells to be raised from the sea-bed and the divers signalled to return at once to the surface.

The pipes which convey the air from the reservoir to the various appliances, being used under water, are made of very thick rubber in which spiral wire is embedded in order to strengthen and prevent it from being even momentarily closed by the pressure of the surrounding water.

The dynamo which supplies the electric current for lighting the bell and the divers' lamps is of the usual pattern and needs no description here, but the twin electric cables are specially insulated for

submarine work, and the lamps used both in the bell and by the divers are usually of 50 candle-power each.

Near by the compressor and dynamo rooms stands the Titan crane in common use in almost all branches of engineering. This steam-driven monster is used not only to raise and lower the diving-bell, but also to move into their places the gigantic concrete blocks used in submarine foundations, and is capable of handling with ease almost anything up to about 50 tons in weight.

Lastly, we arrive at the "submarine telephone exchange," where the wires from the bells, divers, compressor, dynamo, and crane-rooms, and chief engineer's office centre. Here one diver can be put in communication with another, the "crane" can ask the "bell" if it is down too deep, and the chief engineer can talk to a diver working, perhaps, a mile distant on the sea-bed. When the Naval Harbour works at Dover (England, S.E.) were being constructed, it was possible to speak direct from the Admiralty at Whitehall to the divers laying the foundations of the breakwaters on the sea-bed of the English Channel.

CHAPTER XIII

SUBMARINE CONSTRUCTION

THE work of the submarine engineer may be divided into three sections, each of which is really a science in itself and has its own professors or specialists. The first is covered by the word "salvage," which has already been dealt with; the second is "construction," the subject of this and the succeeding chapter; and the third section is "demolition," which will be dealt with later. There are, of course, numberless other "jobs" which the submarine engineer and his right-hand man, the diver, are called upon to do, such as the work performed on shipboard and in wells and mines, but these may be reckoned as subsidiary to the three great divisions of the submarine branch of engineering science. During recent years, however, a fourth, and even more important branch, has been added to the already heavy and difficult task of the engineer; this is submarine boat construction, about which, however, more anon.

Before going further, let us pause for a moment to consider the vast amount of submarine construction now undertaken, and its diverse character. Foremost comes the building of harbours, docks, and breakwaters; stupendous works which the

organised effort and skill of several thousand men can seldom erect within two or three years. The Libau Harbour works (Port Alexander III), Russia, affords a brilliant example of the gigantic nature of such works. The main pier of this harbour is a mile and a quarter in length, and its breadth is 36 feet at the bottom and 24 feet at the top. It is constructed throughout of concrete blocks, weighing from 25 to 30 tons; and the depth of water at the pier-head exceeds 35 feet. The protecting breakwater, which is three and a half miles in length, has six heads, making three harbour entrances, and each head is composed of 300 concrete blocks. These works enclose five square miles of water, and in the pier itself there are no less than 15,753 immense blocks of concrete. All this is, of course, in addition to the temporary staging and piers required for the purposes of construction.

One British diver, Mr. James Murphy, and an assistant, sent out by Messrs. Siebe, Gorman and Co., trained for under-water work thirty-seven Russian masons, and, notwithstanding the rigorous winter climate, the whole of this gigantic work was completed in three years and nine months.

In order to realise the number of these huge harbours, and the almost incessant demand for the extension and improvement of the shipping accommodation afforded, we have only to consider for a moment the ocean-girt British Empire, with its almost countless ports of call in all quarters of the

globe, and the thousands of miles of harbour-dotted coastline of the two Americas, to arrive at a full understanding of the vital importance to the community of this branch of submarine engineering.

The form in which a harbour is constructed depends so much upon the configuration of the coast, the tides, and prevailing winds, as well as the

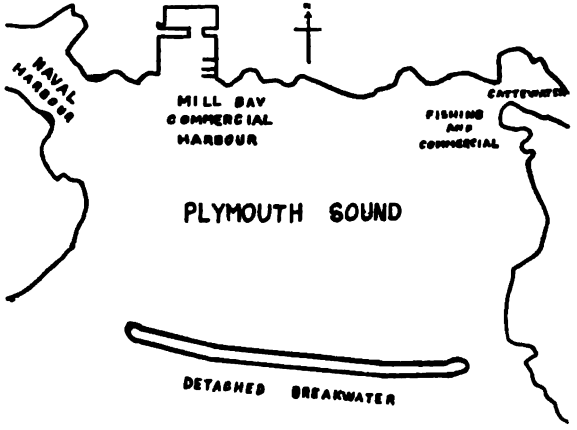


FIG. 29.—Plymouth Sound. Showing the system of protecting a deep-water inlet by a detached breakwater. A natural harbour of the first class.

purposes for which it was intended (naval, mercantile, or fishing), that no general rules can possibly be laid down. A natural harbour, that is to say a sheet of deep water, well-sheltered by surrounding land and unaffected by abnormally strong currents and winds, with an adequate entrance not blocked by immovable sand-banks or rocks, such as Plymouth Sound, naturally takes much less artificial work to make it safe and convenient for shipping

than does a more open position. Likewise the mouth of a broad and deep river is more easily converted into a well-protected harbour entrance than a mere indentation of the coast line.

The usual methods employed in protecting the entrance to a harbour is to screen it from strong currents and heavy seas by concrete piers and breakwaters. The accompanying diagrams will make clear the broad outline of the principles involved.

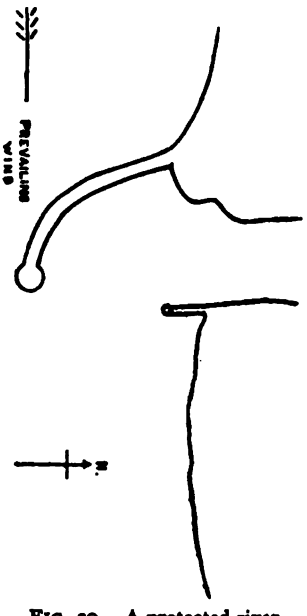


FIG. 30.—A protected river mouth.

When the sea-bed of the proposed harbour site has been carefully surveyed by divers, the nature and direction of the piers and breakwaters is decided upon. First of all, after the plans have been drawn, light temporary piers are erected. For this purpose screw-piles are often employed to support the staging. These are the long iron columns, with a large screw-thread on the bottom end, so frequently used to support seaside piers. They are put down into the sea-bed and screwed round, and so driven deep into the ground just as a screw is driven into a piece of wood. In some cases, however, the ordinary pile, a metal or wood column with a

pointed end, is used. When this is the case, instead of being *screwed* into the sea-bed they are hammered in like an ordinary nail into wood.

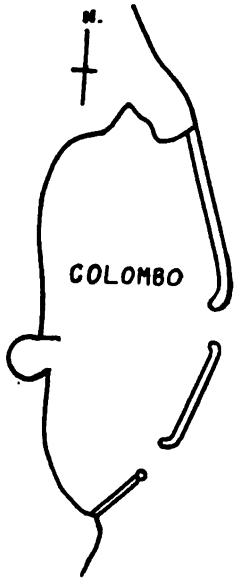


FIG. 31.—Colombo (Ceylon). A semi-artificial harbour formed by the construction of three breakwaters and aided by the configuration of the coastline.

Many of my readers will, doubtless, be familiar with the working of a *pile-driver*, having perhaps seen it in operation at one of the seaside resorts, where the wooden piles of the groynes used to prevent the loss of sand and shingle caused by the tide, the wind, and the waves, are almost constantly being replaced by the aid of the huge hammer. It consists of a vertical wooden frame, up and down which slides a heavy block of iron, called a monkey. This weight is hoisted to the top of the frame by means of ropes attached to a winch; when near the summit, a catch automatically releases the weight from the ropes which are hoisting it, and the arrangement is such that it falls upon the head of the pile, driving it into the sea-bed with an action analogous to that of a hammer (see Fig. 32).

The temporary staging usually consists of a roughly constructed pier, up and down which railway tracks are laid so that the trolleys and travelling-cranes handling the huge concrete blocks can move

with quickness and safety. When this has been built, the work of levelling the sea-bed, so that the foundations of the concrete pier or breakwater may be solid, commences in earnest. This is mostly carried out with the aid of diving-bells and pneumatic tools. As this portion of the operations has

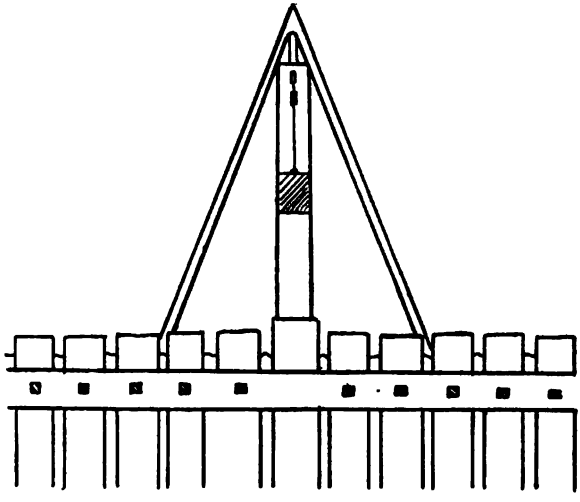


FIG. 32.—A Pile-driver. The metal block or "monkey" is shown shaded. When it has been hauled to the top of the guide it is automatically released, and falls on to the head of the pile.

already been dealt with in previous chapters (see pp. 116–137) no further description is necessary.

Next comes the herculean task of making the large number of immense concrete blocks required for the actual construction of the permanent piers and breakwaters. Concrete, which is formed by mixing stones, either whole or crushed, with sand and Portland cement in suitable proportions, is a

material which is being used more and more every day for purposes of construction. When it is being used for large harbour works, the blocks are mostly "made on the premises." There are several different ways of mixing concrete and forming it into blocks on a large scale, but the essential features

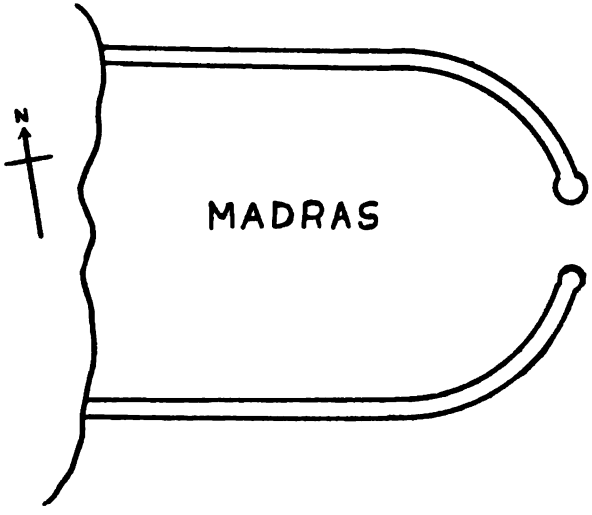


FIG. 33.—Madras. An artificial harbour on an exposed coast-line, formed by the construction of two breakwaters, converging at their outer ends.

of all are the same, the difference being only in the actual method of work. Here I shall describe the concrete-making arrangements employed at the Gibraltar Dockyard Extension Works, which cost Great Britain several millions sterling.

A network of narrow-gauge railway lines were first laid down to facilitate the conveyance of the various ingredients to and from the works. At one

end huge crushers broke up the stone brought in by the railway from the quarries. The trucks were made to run up an incline to the top of the machines. The stone was then tipped into the crushers, to emerge a few minutes later, crushed to the requisite degree of fineness, through a shoot into more trucks waiting for it below. When sufficient of these were filled, they were coupled-up into a train and drawn away to the block-making works.

The process employed for making the concrete blocks is most interesting. On an elevated platform stood heaps, which were constantly being replenished, of all the necessary ingredients — cement, sand, and crushed stone. At regular intervals along this platform were conical-shaped holes or bins into which an army of workmen shovelled the proper proportion of each ingredient. When filled, a signal was made to a man under the platform, who promptly released the bottom of the bin, and the mass fell through by its own weight into a *mixer* placed directly underneath. The mixers consisted of boxes which were made to revolve eccentrically on two pivots. Water was then added, and the boxes revolved for a certain time to mix thoroughly the contents. When this had been done the boxes were opened over tip-trucks waiting below, and the muddy looking mixture slid into them. The trucks were then run off along one of the lines of rails to the block-making moulds, which covered acres of ground. These were merely wooden cases,

which formed the wet concrete into square blocks and held them until dry and hard.

In order to show the capacity of big concrete-making works, which, it must be borne in mind, are merely temporary arrangements lasting only so long as the work of construction continues, it is sufficient to point out that at M'Call Ferry, Pennsylvania, where a huge concrete dam has recently been thrown across the Susquehanna river, the works were capable of turning out 4000 tons of concrete a day, and that 20,000 tons of material was kept in stock.

We now arrive at the actual constructive stage in the building of harbour-piers and breakwaters. The temporary staging, erected over where the permanent pier is to be built, has already been run out from the shore, and on its deck railway tracks have been laid so that the train-loads of concrete blocks can be moved out over the water as the work proceeds. The supply of concrete blocks is sufficient to commence, and the sea-bed has been levelled and prepared by divers and workmen in diving-bells. There are, however, two other important pieces of mechanism which have not yet received attention—the *titan* and *goliath* cranes. These powerful appliances are used for lifting the concrete blocks from the trucks and lowering them into their places under water.

The drivers of these cranes, which are all worked and moved backwards and forwards along the tracks by steam, are in constant telephonic communication

with the divers adjusting and fixing the concrete blocks under water, and also with the workmen levelling the sea-bed from the diving-bells. It will therefore be seen that the precise moment and position for lowering the blocks is determined over the telephone wires from the divers waiting below to guide them into their places.

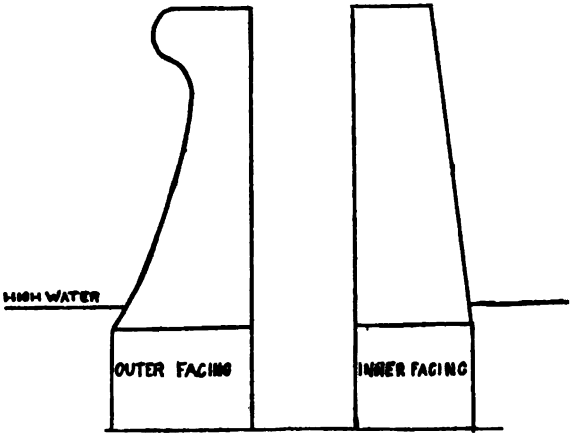


FIG. 34.—Section of a breakwater or sea-wall, showing the curved outer facing.

These huge concrete blocks, often weighing 50 tons each, are built up into the wall just like ordinary bricks. Sometimes they are held in position by iron staples embedded in the concrete and made to dovetail together, and at others merely by cement. The shape of the wall, which is built in tiers, depends upon the power of the wind and sea which it will have to withstand. The most usual form, however, is shown in Fig. 34.

The broad base gives additional strength, and the curved outer facing tends to throw off the spray when the waves beat against them. Inside the harbour the walls forming the actual quays become almost perpendicular so that vessels can lay close alongside, while the face of breakwaters exposed to exceptionally heavy or searching seas is often given a much greater slant in order that the enormous force of the breakers may not be exerted at the moment of impact, as would be the case with a wall perpendicular or nearly so, but expended more gradually on the concrete incline. For the purpose of sea-defence, however, granite blocks are often used instead of concrete for the facings of the wall on account of their greater strength, but where the work is an extensive one the additional cost is frequently prohibitive, and resort is had to "ferro-concrete," which is nothing more than the ordinary concrete "reinforced" by having a network of iron rods embedded to hold it together.

The Foundations of Bridges

One of the most difficult parts of a bridge to construct is undoubtedly the foundations, and it is exactly this part, and this part only, which falls to the lot of the submarine engineer. Let us confine our attentions, therefore, to the laying of these foundations by the methods most frequently adopted.

Much depends upon the depth of water and the nature of the river-bed. It frequently happens that not only is the water deep, but many feet of loose mud and clay cover the harder and more solid stratum on which the actual foundations of the bridge must rest. To get down on to the river-bed and clear this away is therefore the chief difficulty to be faced. Recourse is usually had to a "caisson," or large iron box, inside which, when sunk on to the river-bed, work can be carried on, and which will itself eventually form a portion of the foundations. The use here of a diagram will simplify the task of describing the construction of a caisson, and the manner in which it is used in conjunction with an air-lock.

The caisson is built of steel plates riveted together, and half-way down the interior is a steel floor (*A*), from which an air-tight shaft (*B*) leads up to the surface of the water (*C*). The two chambers (*D*) are filled with concrete in order to make the caisson sink as deep as possible into the mud of the river-bed by its own weight; but the large working chamber (*E*) is open at its lower end, and has a sharp edge all round to enable it to cut into the mud and clay. The air-lock (*F*), which is fitted by an air-tight joint to the top of the caisson shaft, has been described in an earlier chapter.

The *modus operandi* is simple. The whole caisson is lowered on to the river-bed, and the edge of the bottom or working chamber immedi-

ately cuts into the soft mud or clay to a depth of several feet. When it has settled down as far as it will go of its own weight, which by the way is very considerable owing to the concrete already filling the two upper chambers, air is pumped in through the shaft, and the water is thus pre-

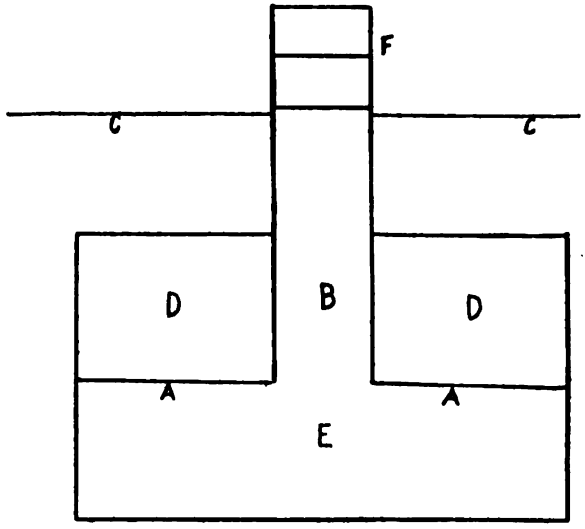
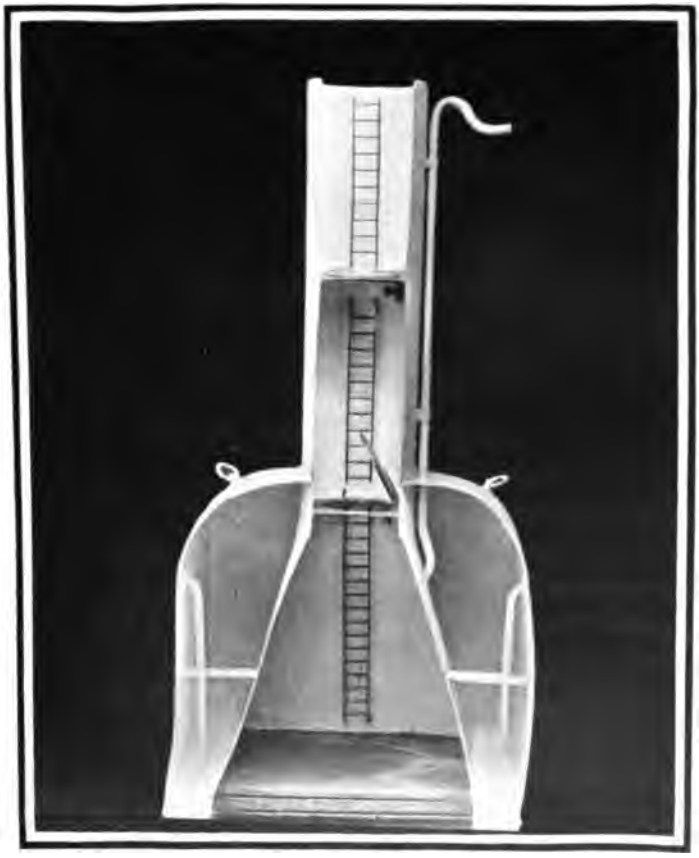


FIG. 35.—Large bridge caisson and air-lock. (Description in text.)

vented from entering the working chamber of the caisson.

The air-lock at the top of the shaft enables men and buckets of dirt to be passed up from the working chamber, resting on the river-bed, to the temporary staging above the surface without allowing any air to escape. It will easily be seen that if this arrangement of air-tight doors was not made,



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THE INTERIOR OF AN AIR-LOCK DIVING BELL

the moment the air-pressure in the caisson was released by men getting in or out, the water would rush up and fill the working chamber.

When the caisson has settled down as far as it will go into the bed of the river, men descend through the air-lock into the working chamber, and commence removing the mud and clay from the inside. As this work proceeds, the caisson gradually sinks deeper and deeper, until its edge reaches a hard stratum capable of forming a solid and lasting foundation.

When this has been accomplished, the whole interior of the working chamber and the shaft leading to the surface is filled up with concrete, thus forming a huge concrete block in a steel casing. But the work does not always end here, for the shaft—which, however, is no longer a shaft, but has become a column of concrete and steel—is encased with stone blocks built up on the roof of the caisson, thus forming the enormously strong stone piers with a steel and concrete core which we see supporting so many bridges.

Among other submarine constructive works must be mentioned the laying of sewerage outfall pipes in the sea, and electric cables, gas and water mains on the beds of rivers. Although, compared with the building of harbours, breakwaters, piers and bridges, they are but insignificant undertakings, their importance and utility to almost everyone cannot be denied.

Submarine Construction

Many readers will have noticed when walking along the seashore at low tide in the vicinity of towns, large iron pipes, supported by wooden trestles well-embedded in the sand or shingle, running down the foreshore and disappearing into the sea. Sometimes the pipes are embedded in concrete, but more often than not they are left bare and merely held in position by stout wooden piles driven into the sea-bed. These, then, are outfall pipes which carry the sewerage some distance into the sea, only releasing it when the tide is ebbing so that it may be carried out and distributed by the currents of the ocean.

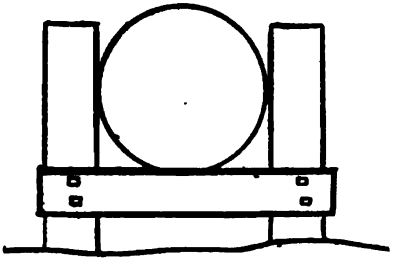

FIG. 36.—Sewerage pipe on trestle foundation.

Few people realise, however, that the laying of these pipes, joining them together, and securing them in position, is often a task of considerable difficulty. In some places quicksands have to be spanned and in others rocks levelled in order that these pipes may be run out at the correct angle at the most convenient spot some little distance from the sea-front of the town which they serve. If, for instance, the set of the tide comes from the south-west, as it does on many parts of the south coast of England, these pipes are generally laid so as to incline in the same direction. This is done

with the primary object of making it easier for the sewerage to leave the pipes when the tide is ebbing.

The formation of the wooden piles or trestles on which these pipes rest is shown in Fig. 36, from which it will at once be seen that the pipes are prevented from sinking into the sand by the wooden cross-pieces, and from being moved to the right or left by the perpendicular piles driven deep into the sea-bed.

About the laying of electric cables, gas and water mains, on the beds of rivers little need be said, for the methods are very similar to those employed in sewerage outfall work. There are, however, many other "odd jobs" which come within the province of constructive submarine engineering, such as the laying and repairing of ships' moorings, cleaning and repairing sluice-valves and dock-gates, and sinking cylinders in wells, &c., but needless to say none of these has the same importance as pier, bridge, and harbour construction.

CHAPTER XIV

SOME WONDERFUL SUBMARINE WORKS

WHEN one comes to consider the vast amount of submarine work now undertaken, and in many cases the stupendous character of the operations, it is impossible to help wondering at the success which has crowned the efforts of man in his struggle with the sea. The annals of submarine construction contain as many, if not more, remarkable achievements than those of any other branch of engineering science, and to choose examples for description here is a task of no little difficulty, as all seem to put forward some important claim to recognition. Many—such as the Dover Naval Harbour Works—have, however, already received so much attention, and their special features have in consequence become so well known, that it seems preferable to deal here with a few equally large and difficult undertakings which are less known to the reading public. Let us first take the Rio de Janeiro docks.

Although Rio de Janeiro, the federal capital of the United States of Brazil, always possessed, in its beautiful isle-dotted bay enclosed by strangely picturesque mountains, one of the largest and best anchorages on the American continent, it has always been the ambition of its cosmopolitan

inhabitants to obtain the benefits accruing from a perfect dock system which would enable the rapidly increasing number of vessels using this port to approach the quays alongshore to load and unload. For many years plans were continually being brought forward and postponed, until at last, in March 1904, the work was commenced by the well-known London firm, Messrs. C. H. Walker & Co., under contract with the Government.

The vast area of operations and the peculiar difficulties of the task of making a first-class dock system from the "raw material" is, perhaps, better illustrated in this work than in many similar undertakings, for although breakwaters or sea defences did not form part of the scheme—as is usually the case—owing to the sheltered position of the bay, the coast-line itself had to be extended into the water, hills levelled, and swamps filled in.

The operations may be divided into seven sections: (1) the draining of the low-lying, swampy portions of the coast-line by the extension of the Mangue Canal; (2) the building of a stone quay about two miles long, on the sea side of which there must be a depth of water sufficient for steamships of any draught; (3) the filling in of the water space comprised between the quay and the actual shore, which in places exceeded 270 yards in width, with a depth of water varying from 10 to 20 feet; (4) dredging a channel about 300 yards broad in front of the quay to a depth sufficient for ships of all sizes to come alongside at all states of the tide; (5) the

formation of an avenue on the reclaimed ground behind the quay wall about 120 yards in width, of which 30 yards was reserved for railway tracks, 40 yards for import and export storage houses, and offices of the administration, and 50 yards on the land side for a public avenue, well paved, lighted, and lined with trees; (6) the equipment of the quay

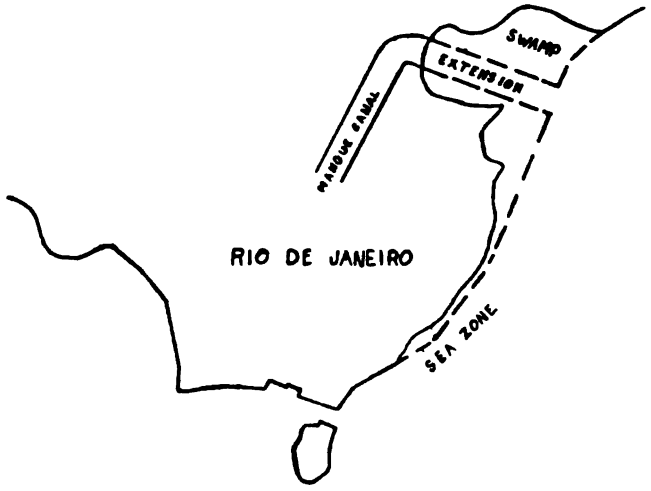

FIG. 37.—The original aspect of the site of the Rio de Janeiro Docks.

with the most modern machinery used for loading and unloading ships, and the erection of two electric stations for furnishing the necessary light and power; and (7) the utilisation of the neighbouring islands as depôts for the storage of inflammable goods, coal, customs, and other port works and requirements. A reference to Figs. 37 and 38 will make clear the principal features in the plan for the construction of this large port.

The work of dredging for the foundations of the quay wall was commenced in March 1904, and by the following January had been completed sufficiently for the construction of the first section of the quay, 600 yards in length, to be commenced.

As the caisson system was the one adopted, little need be said here about the construction of the

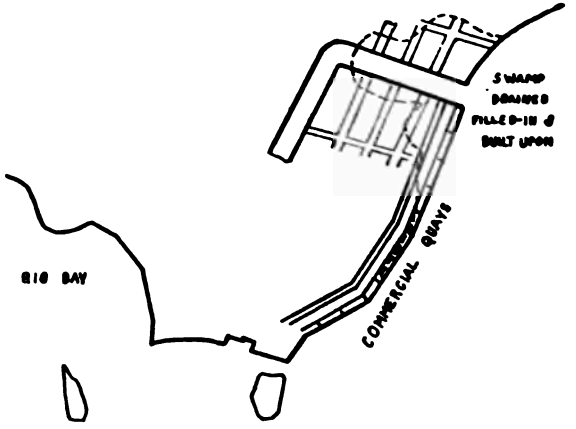

FIG. 38.—The Rio Commercial Docks, showing the swamps drained, the foreshore extended and the intervening spaces filled in, and the quays, canals, and streets constructed.

wall, for this method has been fully described in an earlier chapter (see pp. 148–151. Each of the iron caissons had, however, four shafts instead of one for communication with the surface, and the men in the compressed-air chamber on the sea-bed worked in groups of 12 or 18, with eight-hour shifts. When the excavations inside the working-chamber had been carried out, and the caisson had sunk through the soft layers of the sea-bed on to the solid subsoil.

the whole interior was filled with concrete and the wall built up on top. This process was repeated with every caisson employed, each being placed end-on to the previous one and forming a section, about 75 feet in length, of the foundations of the quay. The completion of the upper part of the wall was carried out during low tide, the height of this, from the top of the caisson to the promenade, being 45 feet, and the width at the top about 12 feet.

It took about 10 days of 24 working hours for each caisson to be lowered into its final resting-place and then filled up with concrete. The excavations in the working-chamber were made either by hand or on the syphon principle. When projections of rock not of sufficient area to form the final resting-place were encountered they were broken up by small explosive cartridges and the disintegrated rock carried up in buckets through the shafts and air-locks to the surface, emptied into barges, and dumped later between the quay and the actual shore.

The filling-in of this extensive "sea zone" involved great labour. The enormous supply of material required was obtained from the Senado Hill, which was completely levelled in order that the maritime quarter could be extended, and also from the sand-banks in the bay until they were covered by an average depth of about 30 feet of water. Thus the work of filling up the water zone comprised between the quay wall and the actual

shore fulfilled four separate purposes: (1) the extension of the dock-side, (2) the utilisation of the hitherto valueless foreshore, (3) the levelling of the Senado Hill and thereby the opening up of new thoroughfares and building ground, and (4) the abolition of the dangerous sand-banks in the bay. Several hundred thousand cubic metres of earth were also taken to fill in the first section from the hills forming the islands Moças and Melões.

The various workshops, concrete-making yards, and depôts were established on the numerous islands in the bay. The work was completed in 1910, having occupied only six years.

Alongside the quay, which is supplied with the most up-to-date machinery for loading and unloading vessels, are the covered wharves, next comes the space reserved for railway tracks, and beyond this a public thoroughfare 130 feet broad, well paved, lighted by electricity, and bordered by trees.

The extension of the *Canal do Mangue*, which half encircles the western portion of the Federal capital, has also been completed. The vast swamps which it has drained were at one time the cause of pestilence. This great work affords an excellent example of what can be done in swamp reclaiming. The canal, which is faced with stone, is about 3 miles in length, 60 feet in breadth, and 10 feet in depth. The ground through which it was cut was so unstable that posts 60 feet in depth had to be driven in to steady it until the water could be drawn off and a solid foundation formed. This

wonderful canal, cut through a pestiferous swamp, has not only drained the surrounding country, but acts also as an outlet for the rain-water, and for the many small rivulets coming down from the highlands behind the city. On either side of the canal are avenues of trees and paved walks, and it is crossed at many points by quaint little rustic bridges.[1]

The North Tyne Pier

The reconstruction of the North Pier at the entrance to the River Tyne (England, N.E.) affords one of the best examples of breakwater work on a large scale at a point on the English coast-line exceptionally exposed to the most violent storms. Records show that during some of the worst gales the waves have reached a height of 35 feet from trough to crest! It will therefore be quickly realised that only the most solid of structures could be expected successfully to withstand for any length of time the terrific onslaught of such mighty billows.

The old North Pier, commenced in 1852, was 3189 feet in length, and terminated in a depth of water of about 40 feet. It is necessary to say something here of the construction of this old pier in order to compare it with the new structure, and the use of a few diagrams will greatly simplify the task of description. The foundations were laid on

[1] For a description of modern Rio, see *The United States of Brazil* and *The Great States of South America*, by Charles W. Domville-Fife.

a rubble mound instead of being sunk in (see Fig. 39), and the pier itself was composed of two masonry walls connected at intervals of about 25 feet by transverse walls; the intervening spaces in the shore half being filled with debris, and in the sea end with concrete; while the foundations on the rubble mound were afforded additional protection

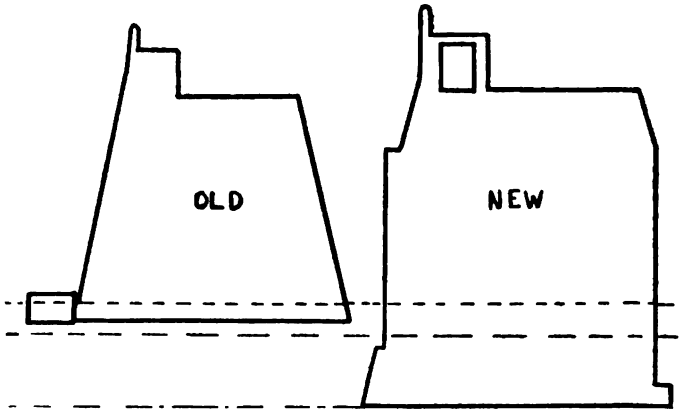

FIG. 39.—Section showing the difference in the foundations and shapes of the "Old" and the "New" North Tyne Pier.

from the suction of the sea by concrete blocks of 30 tons weight.

For many years this immense breakwater withstood the action of the sea, although the summer months were usually fully occupied in repairing the damage caused by the winter gales. This state of affairs went on until 1894, when it was discovered that some of the 30-ton concrete protective blocks had been displaced, and the submarine foundations were in jeopardy. Measures were at once taken

to repair the damage, and after being "patched-up," it held more or less successfully until the summer of 1906, when a serious state of affairs was disclosed. It was then decided to fill an old vessel with concrete and sink it in such a position as to protect the divers while extensive repairs to

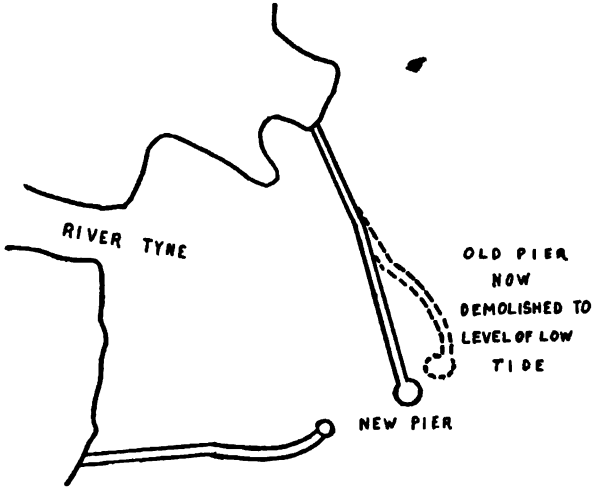

FIG. 40.—The reconstructed North Pier which shields the entrance to the river Tyne.

the foundations were being carried out. This was immediately done, but during a great gale in January of the following year, over 100 feet of the pier was breached by the seas, the huge concrete blocks falling outwards at all angles, leaving the head with its lighthouse entirely cut off from the land.

The extensive damage caused along the whole seaward half of the pier made the rebuilding of this portion absolutely essential, and the question

immediately arose as to which was the most effective, and at the same time least costly, plan of operations. To have rebuilt on the same site would have necessitated the demolition of the wrecked sea half of the old pier and the building of the new one while exposed to the open sea. It was therefore decided to extend the sound shoreward half of the old pier, building the new section under the lee of the old works (see Fig. 40).

Little reference need be made here to the actual work of reconstruction, as it differed but very slightly from the method of harbour construction described in the previous chapter. The main points, however, in which the new pier differed from the old were as follows: the foundations were sunk down about 20 feet through the rubble on to the solid shale, which was dressed level by bell-divers; the whole structure was composed of concrete blocks faced on the seaward side with granite, and a tunnel was made in the upper promenade to afford continuous shelter to those compelled to traverse the pier in all weathers. The lowering of the foundations and the use of concrete blocks with granite facings have made the new pier a much more solid and durable structure than the old, and it certainly needs to be, having, as it does, to withstand some of the worst seas which beat on the stormy coasts of Britain.

CHAPTER XV

SUBMARINE BLASTING

We now come to the third of the sections into which submarine engineering has been divided. It may be said to consist almost entirely of the removal of obstructions to navigation, although there are occasions when the work of demolition must precede that of construction, as, for example, when large masses of rock have to be levelled or blasted away before the foundations of breakwaters and bridges can be securely laid.

When a vessel runs ashore, strikes a rock, or through other cause becomes an exposed wreck, it is the submarine engineer, in conjunction with the maritime authorities, underwriters, and owners, who must decide what is to be done. In most cases the wreck must either be salved or blown up, and if the cost of the former is too great, the latter alternative must be adopted in order to prevent it becoming a danger to navigation. This, of course, does not apply to vessels sinking in the open sea, or where there is sufficient depth of water to make it either impossible or unnecessary to do anything.

This, then, is one portion of the work of submarine demolition, the other is the removal of rocks which obstruct the waterways largely used by ship-

ping. It is, of course, quite impossible to remove the great barriers of the ocean, but masses of rock of considerable size have been blown to pieces and dredged up when they have proved a continual menace to shipping in narrow highways. The work of rock-blasting is not only expensive and protracted, but often very difficult to carry out, especially where the depth of water is great. This class of work is therefore mostly confined to the shallow waters near the coast and the great harbours and rivers of the world.

The importance of removing dangerous rocks which are accessible to the diver as soon after their discovery as possible has been so frequently demonstrated by disasters that it is scarcely necessary to emphasize it here. A notable example of this was the removal of the Elderslie Rock in the Clyde. Although this work was carried out as far back as 1885, it still offers not only a good example of the necessity for such works, but also of what can be done in this direction by continued effort spread over a number of years.

Although in 1750 a shallow ford, then called the Blawarthill Sand, was known to exist in the Clyde channel a short distance above Renfrew, it was not until the s.s. *Glasgow*, one of the first steamers trading between Glasgow and New York, knocked a hole in her bottom while passing this point that the existence of a rock was discovered. At first it was thought that a large boulder might have been responsible for the damage, but contin

borings showed that it was no mere boulder but a huge rock, extending over an area of the river-bed, nearly 1000 feet in length by 320 feet in breadth.

For many years boring from a movable stage and blasting by gunpowder was carried on. By 1869 the rock had been lowered, at a cost of £16,000, so as to give a minimum depth of water of 14 feet over one half of the channel and 8 feet over the other half. It was not until 1880, however, that a decision was arrived at to remove the rock so as to give a uniform depth of at least 20 feet of water at low tide over the whole channel. Work was carried on with diamond drills for boring, and dynamite, blasting-gelatine, and tonite for explosives for five years incessantly, the broken rock being brought to the surface by a dredger and the ground afterwards levelled with the aid of diving-bells.

Some idea of the labour involved may be gathered from the fact that about 16,000 holes were bored in the rock for inserting the explosive charges, 76,000 lb. of dynamite and other explosives were consumed without loss of life, 35 miles of electric cable and shot-hole wire were required for connecting the charges with the exploding machines on the barges above, and about 110,000 tons of rock and clay were dredged. The whole of this gigantic undertaking, which did not cost more than £70,000, was carried on in all weathers without interfering with the ceaseless day and night traffic passing up

and down this important river. The rock-drills used were driven by a steam-engine on the surface, the rotary motion being given to the drills by means of bevel wheels working in a frame, and connected with the engine by an ingenious arrangement of ropes and loose pulleys, which allowed for the movement of the engine-barge caused by the rise and fall of the tide, the rough weather, and the suction of passing steamers. Eight drills were in use at one time, and, while the boring was in progress, water at a pressure of 40 lb. to the square inch was forced down through the hollow boring rods to wash out the detritus and cool the face of the diamond crowns.[1]

It must, however, be pointed out that the whole of this great work was carried out without the powerful aid of the more modern pneumatic rock drill and the submarine telephone. The first of these appliances would not only have greatly simplified the task of boring the holes for the charges, but also have increased the speed of the work by at least 40 per cent., while telephonic communication between the divers setting the drills and charges and those operating the driving engine and firing the explosives on the surface would, undoubtedly, not only have enabled greater economy of material but also of time. More recent undertakings have proved that with modern machinery and appliances that which took five years to accom-

[1] Taken from a paper read before the Institution of Naval Architects.

plish in 1880 could be done now in less than half the time with the same amount of labour.

The methods employed in submarine rock blasting do not vary greatly, although the size of the rock to be removed and the depth of water covering

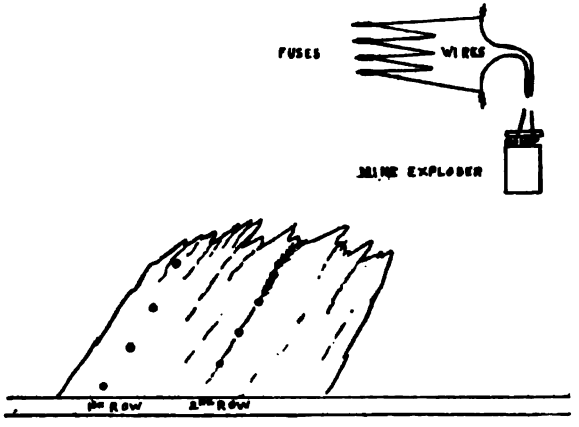

FIG. 41.—Sketch showing the position of the first and second row of holes drilled in a submerged rock for blasting charges. It will be seen that in the second row advantage has been taken of a fissure in the rock. The small diagram shows the simplest arrangement of electric wires and fuses.

it necessarily have a certain influence over the exact manner in which the operation is performed. If the rock has perpendicular sides the holes are usually drilled in rows parallel to the edge but some little distance from it, and when this line has been blasted away a second and third row is drilled and blasted in the same manner, until the whole top of the rock is removed, when the opera-

tion can be repeated on a lower level until the required depth is reached (see Fig. 41).

The advantages possessed by this vertical method over the horizontal one is that the presence of seams and fissures in the rock can be detected and used in the next series of blasts to produce without boring the greatest possible effect.

The first thing to be done in submarine rock-blasting is to moor the working vessel over the rock. Divers then descend and choose the best position to commence the blasting. The pneumatic drills are lowered, and the divers fix them in position and signal for the compressed air supply to be turned on. When the first series of holes has been drilled to the required depth the diver in charge telephones for the explosive charges, which have been prepared with watertight detonators, and are joined to the insulated wires connecting with the electric battery on the surface. As a safeguard, however, the wires leading from the charges should not be actually connected to the batteries until all is clear for the explosion. The charges, which are usually made up into cartridges with metal cases, are then inserted into the holes drilled in the rock and the openings sealed up with clay, which is called the *tamping*. After examining the connections of the electric wires the divers return to the surface, the drills are hauled up, and the working vessel is towed to a safe distance. The wires leading up from the cartridges are then connected with the electric exploding machine or

battery, and the charges fired by the simple turning of a handle and the establishment of the electric current. A shock followed instantly by a second and more powerful one and accompanied by an upheaval of the water is the only result noticeable on the surface, but if the charges were powerful ones and were properly laid, tons of rock will have been shattered and broken from the mass by the

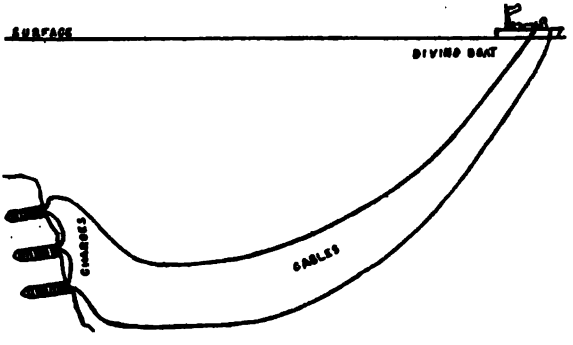

FIG. 42.—A series of charges ready for firing.

one series of explosions. The disintegrated rock is quickly cleared either by divers, or later, when masses have accumulated, by dredgers in the same way as mud, sand, and shingle is removed from harbour bars, the sea-floor eventually being levelled by men in diving-bells. A reference to Fig. 42 will enable a clear understanding of the operations described to be obtained.

It is easy to see that this process has only to be repeated in order gradually to break up the whole rock or else reduce it to a level that will enable the

largest vessels to pass over it at the lowest possible tide.

The Dispersal of Dangerous Wrecks

The dispersal of a wreck, although sometimes difficult of accomplishment when it lies in an exposed position, can mostly be carried out with less

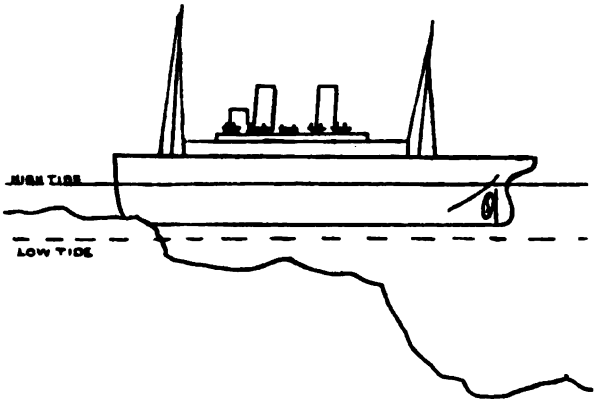

Fig. 43.—Sketch showing steamer on the rocks at high tide.

labour in a fraction of the time occupied in successful rock-blasting. The method of laying and firing the charges is so much like that just described that little more need be said. When blowing up a wreck, however, the charges, which are often laid in the form of a belt round a section of the vessel, are usually much heavier, frequently amounting to 25 and even 50 lb. of dynamite or other explosive.

The conditions vary to such an extent that it is quite impossible to lay down any hard and fast rules for the dispersal of a wreck. As in all

branches of submarine engineering, much is left to the discretion and ingenuity of the engineer in charge of the operations. Let us take the case of a wrecked vessel lying astride a rock or sand-bank with her back partially broken, in addition to being battered in such a manner as to make her salvage quite impossible. This is by no means an unusual condition. When fog covers all around and a vessel is proceeding ahead, cautiously groping her

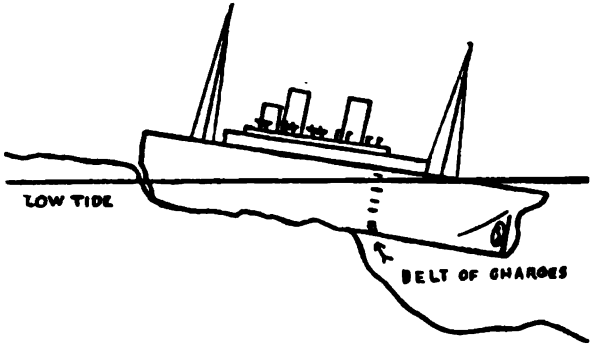

FIG. 44.—Settling down with the tide into a hopeless position.

way in shallow seas amidst other shipping, as, for example, in the English Channel, she frequently gets out of her true course in trying to avoid other vessels. These can only be located by the blasts of their whistles and syrens, which are most deceptive, as in the curious atmospheric conditions which pertain during a thick fog all sound seems dulled. It is at times like these when a vessel is most likely to strike a rock or run ashore, crumbling and tearing her bows and often remaining fixed. When the tide falls, the vessel sinks or "sits down" on

lower rocks with one or other section overhanging deep water, as will be seen in Figs. 43, 44. The back of the ship is broken, and she becomes a total wreck.

As in all technical questions, the opinions of engineers as to the best method of dealing with a

FIG. 45.—Section showing arrangement of fuse, detonator, and explosive in a large blasting charge suitable for submerged wreck dispersal.

wreck of this character would differ widely. Some might think it possible to save the stern section by cutting the damaged portion away, others would probably be ready to stake their careers on the impossibility of the task. For our purpose, however, it is sufficient that all thoughts of saving any portion of the vessel have been abandoned, and it has been decided to blow her up. The

explosive charges are placed near the weakest points, which in this case is amidships. At the first series of explosions, the stern half of the vessel would probably be severed and glide back into deep water. The two pieces could then be destroyed separately by further blasts. It is seldom, if ever, possible to completely disperse a wreck with a single explosion, however great the force, although cases have been known where a well-placed charge had done so much damage that the remainder of the task was rendered comparatively simple. This is, however, an exception to the general rule; it mostly happens that several hundreds of pounds of explosive are used in the dispersal of a wreck of even moderate size.

CHAPTER XVI

THE SALVING OF SPECIE

ALTHOUGH in magnitude the salving of specie cannot be compared with harbour construction and rock-blasting, it nevertheless forms an important part of submarine work, and is surrounded with an interest and glamour all its own.

It is here that the deep-sea diver is often called upon to face the greatest risks and penetrate to the greatest depths, fortunes frequently depending upon his success. None but experienced men can accomplish this kind of work in any but shallow water, as not only must the interior of the wrecked vessel be penetrated, but it frequently happens that the treasure is contained in a strong room, entry to which can only be gained by the use of dynamite or other explosive in such a manner as not to disturb or damage the contents, but only to burst open the door. This, to the uninitiated, may sound a comparatively easy task, but when it has to be carried out in a depth of from 100 to 180 feet of water, in seas perhaps infested with sharks, octopuses, or other dangerous reptiles of the deep, it becomes a task which even the bravest might well fear to undertake.

The recovery of sunken treasure being, for all

practical purposes, exclusively the work of the individual diver equipped in the most modern pattern deep-sea dress, it will enable a better understanding of this work to be obtained, and at the same time be more interesting, if some of the most noteworthy feats of specie salving are described here in the place of methods which are only applicable in certain instances. How one and a half millions sterling in gold and silver coin and bars have been wrested from the sea can scarcely fail to interest the most indifferent inhabitant of these essentially maritime islands.

One of the most remarkable feats in the annals of submarine salvage was the recovery of £90,000 in Spanish gold coin from the wreck of the mail steamer *Alphonso XII*, of the Lopez Line, outward bound from Cadiz to Havana, which foundered off Point Gando, Grand Canary, in 160 feet of water. This vessel had in her bullion room nine small wooden chests containing the specie, and when the news of the wreck and the loss of the treasure reached England, where the specie had been insured, the underwriters dispatched an expedition in the salvage steamer *Arabian*, under the command of Captain Stevens, employing Alexander Lambert, the hero of the Severn Tunnel (see p. 90), to essay the dangerous task of descending 160 feet on to the deck of the submerged vessel, breaking into the treasure chamber, and sending the gold to the surface.

Little hopes of success were entertained owing

to the great depth of water and the exposed position of the wreck, but after several unsuccessful attempts Lambert succeeded in reaching the sunken vessel and getting into the bullion room. The exact words of the first cablegram received in London from Captain Stevens notifying this success is worth giving here: "Lambert has got both scuttles open and has got into the magazine. The boxes of gold are there."

Owing to the wreck lying in a very exposed position, and the difficulties and dangers of deep water and strong ocean currents, the work of salvage occupied over six months, but during that time the nine treasure chests, containing coin to the value of £90,000, were brought safely to the surface.

In the warrant-officers' mess of H.M.S. *Excellent* at Portsmouth there may, I believe, be seen a painting, presented by Messrs. Siebe, Gorman & Co., of Lambert in the treasure room of the *Alphonso XII.*

At the enormous depth of 160 feet the pressure of water on the diver's body exceeded 69 pounds to the square inch. This feat of nerve and endurance is considered by divers to be one of the record treasure dives.

Over £4000 an hour was the speed of the recovery of Mexican dollars from the wreck of the ship *Hamilla Mitchell.* When this vessel struck the Leucona Rock, near Shanghai, £50,000 in coin and specie disappeared beneath the sea.

Lloyds' agent, who was instructed by the under-

writers, visited the scene of the wreck and pronounced both the cargo and treasure irretrievably lost on account of the depth of water and dangerous nature of the surrounding high rocks. Undeterred by this opinion, however, Captain Lodge undertook the task, and proceeded to Shanghai, accompanied by the two experienced divers, R. Ridyard and W. Penk, with a complete set of deep-sea diving gear supplied by Messrs. Siebe, Gorman & Co. On arrival at Shanghai Captain Lodge engaged the pilot cutter *Maggie*, and sailed in search of the wreck.

When the approximate position was reached it was found impossible to carry out operations from the cutter, which was prevented from going sufficiently close to the rocks, so a small open boat was used to convey the diving party. After a prolonged search in depths varying from 120 to 160 feet, the divers succeeded in finding the wrecked vessel, which had broken in two, the after part, containing the treasure, having rolled into deep water.

It appears that when this unfortunate vessel struck the rocks and foundered she at first rested on a ledge, but subsequent rough seas caused her to part amidships, the stern section slipping from the rocks and sinking in 160 feet of water.

With considerable difficulty not unattended with danger, Ridyard succeeded in getting into the treasure-room. Here he found some of the dollars lying about in heaps, worms having eaten the wooden boxes in which the coin was packed. Four

times did this plucky diver descend to the wreck, on the last occasion working for four hours consecutively at this great depth, a feat never previously performed by any other, and sending safely to the surface the contents of 64 boxes of treasure.

Returning to the boat completely exhausted after his long submersion, Ridyard expressed keen desire for water to quench his thirst, and Penk offered to go ashore and fetch him some from a spring high up on the rocky island. While filling the bucket he noticed, much to his astonishment, a large number of white sails coming out from the mainland, and growing suspicious, owing to their number and to the fact that they were native craft, hastened back to the boat with the information. Captain Lodge identified them as several hundred piratical junks, who had by some means heard of the treasure on board the little craft and were bearing down upon them, and gave orders for the anchor and chain to be slipped immediately. The breeze being light they were obliged to make use of the oars, and Ridyard, although in a terribly exhausted condition, pulled for some time until a breeze sprang up and they were able to make sail. Reaching the cutter, they stole safely back to Shanghai under the cover of night.

The Shanghai newspapers attached great blame to the authorities for not affording them protection, as, owing to this interruption, only £40,000 in value was brought to the surface. A year or so later,

however, a second expedition was organised and the remaining £10,000 recovered.

Although in point of value the specie recovered from the wreck of the steamer *Skyro* was of minor importance compared to that recovered from many other wrecks, the difficulties which surrounded the task of salvage makes it worthy of mention here as an example of what can be done, even at great depths, by a skilled and daring diver.

The *Skyro*, which had on board bar silver to the value of £9000, was on a voyage from Cartagena to London. When approaching Cape Finisterre, the weather became foggy and the vessel struck the Mexiddo Reef, passing over it, but foundering twenty minutes later about two miles off the coast in 180 feet of water.

The first expedition, which was dispatched a few months after the disaster, failed to recover the treasure, but in the following year (1895) Mr. J. K. Moffatt of Bilbao undertook the task. Many months were spent in further operations without success, and the work had to be again suspended owing to rough weather setting in. At the third attempt, which was made in the following year, more powerful diving apparatus was used, and resulted eventually in the recovery of 59 bars of silver valued at £9000.

During these protracted operations the working depth was seldom less than 171 feet, and it frequently amounted to 180 feet, at which the pressure of water exceeded 78 lb. on the square inch. In

order to gain access to the cabin in which the silver was stowed, the deck had to be blown away with dynamite, a task which proved very difficult owing to the boisterous state of the weather. The approach of winter caused the operations to be again suspended, but they were resumed some months later, with the result that the whole of the specie was recovered.

The *London Times*, commenting upon this remarkable achievement, makes the following observations: "When one takes into consideration the wild and exposed position of the wreck, which lies about nine miles south from Cape Finisterre, the strong currents that prevail in the locality, the rough weather that had to be contended with, the fact that the diver had to use dynamite to effect an entrance into the cabin where the silver bars were stowed, and that the deck was collapsed to within 18 inches of the cabin floor on the starboard side of the silver, some idea of the dangerous nature of the undertaking may be realised. The diver reports that there is now no part of the wreck, fore and aft, standing higher than himself excepting the engines and main boilers, it being just a heap of old iron. To Diver Angel Erostarbe is due the greatest praise for the indomitable pluck he has displayed in carrying out this most difficult submarine operation."

A little idea of the value of treasure recovered by divers may be gained from the following few additional instances of fortunes raised from the

sea-bed: 36 boxes of bar gold and silver from the wreck of the steamship *Carnatic;* treasure to the value of £250,000 from the s.s. *Malabar*, and specie valued at £120,000 from the good ship *Queen Elizabeth.* Divers have, during the past half-century, wrested from the mysterious depths of the ocean enough specie to fill at least one of the bullion rooms of the Bank of England.

CHAPTER XVII

SOME SUBMARINE INDUSTRIES

Of the three submarine industries, pearl, sponge, and coral fishing, the first is the most important, although in point of value sponge fishing has, during recent years, become a good second, mainly on account of the low prices obtained for the mother-of-pearl shell in the European markets.

It is a quite common belief that pearls are the chief attraction of the pearl fisheries, and it may surprise many to learn that such is not the case. It is the shell of the *Maleagrina Margaritifera*, or mother-of-pearl oyster, which forms the backbone of this important industry, although, of course, it is the ever present likelihood that the shells brought to the surface may contain a "pearl of great price," which reconciles many of the fearless divers engaged in this industry to run the risks they do.

Of the pearls actually discovered, more than half are stolen and secretly sold by the native divers employed by the owners of the fishing luggers and schooners. It is quite impossible for the few white overseers to institute any system of search—such as that in vogue on the diamond fields of South Africa—among the hundreds of Japanese, Malays, and other natives engaged in these fisheries. Any

man making the attempt would in all probability lose his life. For this and other reasons, the pearl has become a secondary consideration, the fisheries, as a commercial industry, depending upon the shell of the mother-of-pearl oyster.

The pearling grounds, like the gold-fields, are usually discovered by prospectors. These go cruising round in their small 8 to 10 ton luggers, sending down divers every now and then to search the sea-bed. When shell is found there is seldom any attempt to keep the locality secret. The pearl oyster (classified as the *Avicula Margaritifera*), which is valuable only for the pearl it bears—the shell being of no commercial value—is found more or less in all parts of the world, principally, however, on the coasts of Western Australia, Panama, Ceylon, and parts of Mexico and California. The mother-of-pearl oyster, which produces the largest real pearls and is also valuable for its shell, abounds along the northern coast of Australia, in the Malay Archipelago, and the South Pacific Islands. It is this latter kind which is the principal objective of the pearl fisheries, the shell alone being worth anything from £150 to £250 per ton in the London market, to which most of that collected on the Australian coast is sent. The value of the pearls discovered amounts on an average to about £20 per ton of shell. It must, however, be remembered that, although one fine gem might be worth several thousand pounds, tons of shell are recovered in which there are no real pearls, or

perhaps only a few worthless specimens. From this it will be seen that the fisheries depend almost entirely upon the mother-of-pearl.

The headquarters of this industry on the Australian coast, which has hitherto been the most favoured ground, is Thursday Island in the Torres Strait, off the coast of Queensland. The fishing, or more correctly diving, is carried out from small sailing luggers, which usually cruise over the grounds in fleets with attendant cutters of much larger size, to which they transfer the shell as soon after it has been brought to the surface as possible.

The luggers are manned by a crew comprising the diver, who is in command, one tender, who holds the life-line and attends to all signals from the diver when at work, and four ordinary hands, who work in pairs at the pump when the diver is down. With but few exceptions the whole crew has hitherto consisted of coloured men of various nationalities. The working hands being mostly Malays or aboriginal natives, and the divers Japanese, who are quite fearless and have the advantage of being accustomed to the sea from childhood; but now that the Federal Government has cancelled all licences issued to Japanese and coloured divers the more costly white divers will have to take their place. What this will mean to the pearling industry it is difficult to say.

The crews are paid by results, an average amount earned by a diver in the season, which extends over eight months, being about £150,

exclusive of living expenses and any pearls he may have stolen. The approximate number of men employed in the pearl fishing industry of the Torres Strait is about one thousand.

The great depth to which pearl divers have in certain places to descend makes their work often extremely hazardous. Around Thursday Island, where the deepest grounds are situated, the average depth is 100 to 150 feet, but it is by no means unusual for the most fearless divers to descend to the record depth of 240 to 250 feet! It being quite impossible for the human frame to stand this enormous pressure for long, the divers seldom remain at the bottom longer than four or five minutes, although over an hour is occupied in lowering and hauling them up again, a few minutes' rest at frequent intervals being necessary in order that the change in pressure may be gradual.

To haul a diver quickly to the surface from such a depth would in all probability cause a form of paralysis, known as *diver's bends*, to set in, and death would almost surely result. If, on the other hand, a short rest at different levels is allowed, the danger of this dreaded disease is minimised to such an extent that in the Torres Strait fisheries during each season it seldom happens that more than one diver, or two at the most, lose their lives from any cause, although the waters are there infested with sharks.

The actual operation of collecting the shells is

simple. The diver descends slowly until he reaches the bottom. The water in these seas is usually as clear as crystal, and the sunlight penetrates so deep that he is able to see at once where the shells lie, and he proceeds to collect as quickly as possible as many shells as lie close around, placing them in a net-bag. Divers make only two descents a day, but in places where the water is comparatively shallow they remain on the sea-bed for a very much longer period than where it is deep.

Each lugger takes on an average about 6 tons of shell in the season, of which it may be reckoned 2 tons is clear profit. The number of shells to the ton varies from about 2000 of what are known in the trade as *chicken shell* to 600 of the *ordinary sound* or *wormy* kind. Needless to say, the first of these qualities is the most valuable.

In places, notably on the New Guinea coast, a single pair of shells often weigh from 10 to 15 pounds, but by far the greatest number of those recovered in the Torres Strait fisheries range from 3 to 6 pounds in weight. Although there are various exquisitely tinted shells to be found, from the delicate pale-pink hue occasionally discovered on the West Australian coast and the iridescent golden shell of the South Sea Islands to the large-sized *Tahita black*, the purest white with the most uniform nacreous lining of true mother-of-pearl is that which commands the highest price.

It is a curious habit of the oyster, of which advantage is sometimes taken to obtain artificially

produced pearls, that when any extraneous matter, such as a minute stone or grain of sand, enters the shell and causes irritation, the mollusc immediately sets to work to remove the irritation by coating the particle over with a layer of nacre, or pearl-like substance. The divers frequently insert small pellets into a large number of shells, which in course of time get coated over with a thin skin of pearl. These, when discovered, they sell for the manufacture of cheap jewellery at a price varying from a few shillings to several pounds. Somebody ought certainly to tell the oyster of this fraud.

About the real pearls discovered little can be said, except, perhaps, that by far the largest number are of poor quality and of little value, although occasionally a really valuable gem is discovered.

Sponge Fishing

Almost of equal importance, as a submarine industry, is sponge fishing, which is largely carried on in the Mediterranean, off the coasts of Florida, the Bahamas, and Cuba, and in the East. By far the largest proportion of the sponges of commerce, however, come from the Mediterranean and the West Indies.

Many of the Mediterranean divers still go down naked with a net girded round their waists, and carrying a stone attached to a rope. On arriving at the bottom, they tear off as many sponges as

lie within reach, place them in the net, and signal to be hauled up. This old-fashioned method is often conducted in water up to 100 feet in depth, the divers remaining below from one to two minutes, during which time they must withstand the great pressure, unaided by mechanical appliances, holding their breath and tearing off the sponges from the rocks. The reward for each plunge varies from ten to thirty sponges.

There are, however, many Greeks now using modern diving-dresses in the fisheries among the Grecian Archipelago and on the North African coast. These men often work at the great depth of 200 feet, and are rewarded by some of the finest sponges obtainable, which grow only in the deep waters of the Mediterranean.

When recovered from the sea, the sponge is but little like the finished product of commerce. It is a heavy, slimy mass of dark-bluish appearance, with a strong odour of shell-fish and weed. The pores are filled with a glutinous substance, which is pressed out by a process not generally known before the sponges are laid out in the sun to dry.

In the fishing villages of the Grecian islands hundreds of sponges may be seen lying out to dry, even on the roofs of the little white cottages which fringe the turquoise sea, giving these places a characteristic appearance; but the breeze-borne perfumes are certainly not those of Arabia.

When the Mediterranean is swept by a north wind, the dried sponges absorb so much moisture

that their weight is increased by at least a tenth part. For this reason experienced buyers prefer to wait until the wind changes before making purchases, as all sponges are sold by weight.

The Mediterranean produces the well-known Turkey sponge, the finest specimens of which are obtained off the coast of Tripoli. The three most valuable kinds of sponge obtained in these waters are the *fine Turkey*, the *brown Turkey*, and the *honey-comb*; but owing to the high price of the Mediterranean product a large supply of sponge for the American and British markets is now obtained from the fisheries of Florida, Cuba, and the Bahamas.

About coral fishing little need be said, for it is carried on almost entirely by natives in the most primitive fashion among the atolls of the Pacific Ocean.

CHAPTER XVIII

INTERESTING TALKS WITH DEEP-SEA DIVERS

HITHERTO I have dealt with submarine engineering as a science, leaving it to the imagination of readers to invest it with the due amount of romance, but if the life and work of the submarine engineer is to be truly told, the human aspect cannot be entirely avoided.

There are few professions or trades more exciting or hazardous than that of the deep-sea diver, and many are the tales of peril and adventure which can be told by these veterans of the deep.

Knowing the propensity for "yarns" with which members of all branches of the seafaring profession are rightly or wrongly credited, and this being a book of reference, I closely investigated the following stories of submarine adventure, which are as instructive as they are interesting.

In August 1907 I had the pleasure of a long talk with Mr. J. Murphy, one of the most experienced divers in the employ of Messrs. Siebe, Gorman & Co., the well-known submarine engineers to the British Admiralty.

Mr. Murphy was at first very reluctant to say

much about his adventures, but a little persuasion induced him to tell his story. I will give it here in his own words, but without the rich Irish brogue.

"Would you like to know how I lost that?" said Murphy, holding out his left hand, which was minus a forefinger. "It was while building a breakwater. I was standing on a platform, some distance under water and away from the boat on the surface, guiding huge blocks of granite down steel runners. These blocks often need easing, and I was in the act of steadying one when it stuck fast in the guides. I signalled to the surface asking if there was any reason for the block not moving, but received a reply that apparently there was nothing to account for it. The water was so thick that I could not see a yard ahead, and had switched off my electric lamp, as it was quite useless in the sandy water. I pushed the block and eased it with a crowbar, but still it would not move. Thinking that perhaps something was in the way, I felt with my hand the steel guide, and as I was doing this, the 3½ tons of stone dropped without the slightest warning, tearing my hand and carrying me completely off the platform with the suction. Down and down I went, until I heard the huge block strike the bottom. With difficulty I managed to regain my balance, and commenced groping about. I found the block, and felt to see that it was in its proper place. All this time I was quite unaware of the fact that my hand was a shapeless mass. Just as

I was carefully examining the granite square to make sure that it had sustained no damage, I felt a quick jerk on the life-line and was hauled to the surface. My companions in the diving-boat had seen the blood from my hand float to the surface, and, acting promptly, as is necessary in submarine work, had dragged me to the surface, expecting to find that I was half-dead. My hand gave me no pain for some time, but I fainted from the loss of blood. My finger had to go, and they amputated it at once; but I do not mind now that I am used to doing without it," he concluded with a smile.

"I was once in Ireland—moi own countree—" continued Murphy, with a broad smile, "building a small concrete fishing-pier. The water being shallow, I had been under, setting blocks, for some considerable time, and did not know that a strong breeze had sprung up on the surface. I noticed the water around begin to oscillate, but thought nothing of it. I was sitting on the top of a block of concrete, driving in some iron staples and holding on to the "loose bar," when gradually the block began to move backwards and forwards. I clutched the iron bar, not daring to move. I knew if I stirred, either to signal to the surface or to attempt to get off the block, that in all probability I should get smashed by the other masses of concrete, which, as they were not properly fixed, had also started to move with the motion of the sea. At last I summoned up courage and signalled for

the block I was sitting on to be hauled up to the surface. This was quickly done, and a hearty laugh greeted my appearance from the deep, sitting on the top of the block and clutching frantically the loose iron bar. I did not see the funny side of the incident then, but I do now."

Electrocuted Under Water

Passengers travelling to the Highlands of Scotland, via the Forth Bridge, glance down at the often swollen waters as the train dashes over this magnificent cantilever bridge, little knowing the terrible experience of one of the divers engaged on the submarine foundations.

The ordeal of being electrocuted in 100 feet of water is what befel diver E. A. Rayfield, who tells of this terrible experience in the following words:

"While engaged on the concrete foundations of the Forth Bridge I had what would probably be termed a very exciting experience. I was standing on a narrow platform, about thirty feet under water, carrying in my hand a very powerful submarine electric lamp. Some important work had just been completed, and I was overlooking this when the light from my lamp suddenly went out. Without thinking I placed my free hand on the outer glass shield to ascertain if it was broken, and for some reason, which I have never been able to fathom, the live wire supplying the current from the surface came in contact with the back of my hand. The

shock was terrible, and I lost hold of the guiding-rope and fell from the platform into nearly 100 feet of water in a semi-unconscious state. My mates on the surface, thinking there was something wrong, gave the usual safety signal, and finding that I did not reply and that there was a sudden jerk on the line and air-pipe, hauled me to the surface quite unconscious.

"It may be interesting to tell your readers of the fate of a naval diver while I was engaged on the Forth Bridge," continued Rayfield, ignoring any further reference to his own adventures, which I knew to be many. "This diver was down repairing the moorings for a man-of-war. He was working at the great depth of 140 feet, and owing to the pressure was unable to return quickly to the surface, when the tide came in with a fearful race, dragging him along and in some way severing the air-pipe and life-line. He was never seen again—he was a pal of mine!" concluded Rayfield thoughtfully.

A Close Shave

Mr. Rayfield had another lucky escape while working in a coal-mine in Derbyshire. The large water outlet-valve at the bottom of the shaft became clogged and the water quickly rose to 100 feet. In response to a telegram from the manager of the mine, Mr. Rayfield hastened to the Midlands to attempt to open the valve.

The task was a difficult and hazardous one, as

the shaft descended hundreds of feet into the earth, and at the bottom there was just over 98 feet of water to dive through before the valve could be reached.

"I descended the shaft with tons of water pouring out from the different leads on top of me," said Rayfield, "but I managed to get down all right, although I must confess to a slight feeling of nervousness when it came to plunging into the 100 feet of black coal-laden water which was rising every minute. After groping about at the bottom of the shaft for some minutes, I found the valve and succeeded in unfixing it and bringing it slowly to the surface, but how I did it I really do not know, as the water was like coal-mud, and when nearing the surface it came roaring down the shaft on top of me. Although the choked valve was removed, the water did not go down as was confidently expected. It was a great disappointment to me that I had not succeeded in putting matters right, and I wanted to descend again, but the manager of the mine persuaded me to wait a little time. It was the luckiest thing I have done in my life when I took the manager's advice and waited, for when we returned to the shaft some hours later, sheets of flame were rushing up from the black abyss. My diving-suit, boots, in fact, everything I had left on the platform some distance down were charred to a cinder by the fierce heat."

Rayfield soon procured another outfit, and after the fire had ceased (which only lasted a short time)

he again descended the flooded shaft and successfully completed the task, receiving the grateful thanks of the mine owner for his splendid work.

While writing this I hear with great regret that Mr. Rayfield's career as a diver has been brought to a close, he having met with a serious accident while descending a well, entailing the loss of a leg. Many were the plucky deeds performed by this able British diver in the ordinary course of his duty.

Writing these adventures in the lives of deep-sea divers brings forcibly to mind a little experience of my own. It was one of my first excursions under the sea, and although valueless except as a lesson to the inexperienced, I will give it here for what it is worth.

I was testing a light-weight diving-dress of my own design intended for use in my submarine boat in the event of accident. The sea was calm at the time, and the water barely 18 feet deep. I donned the dress and climbed over the gunwale of the diving-boat, in which were two of my engineers, and descended on to the sea-bed. Although quite a novice, I walked about for some minutes with comparative ease and comfort. My air supply being amply sufficient and nothing unusual happening, I quickly gained confidence and commenced to move about among some rocks. Scarcely had I climbed on to some of the highest to see if my head would then rise above the surface, when my feet seemed to slip from underneath me and I felt

myself falling. I clutched the life-line to signal to the surface, but it was evidently too slack for them to feel the pull. The danger arose, however, from the fact that I was using an ordinary rubber tube, not stiffened or held open by an embedded spiral wire, as is now used in the proper diving air-hose. In falling from the rock I must in some way have twisted the rubber tube at more than one point and so cut off my air supply, for although I regained my feet after a few minutes' effort and commenced climbing off the rocks, I felt a sudden dizziness come over me, and I knew nothing more until I found myself stretched at full length in the boat on the surface. My companions, noticing that I was remaining still rather long, and getting no answer to their signal, hauled me to the surface. I soon recovered, but the sensation on coming to was far worse than anything I felt when under water.

CHAPTER XIX

A MISCELLANEOUS CHAPTER

ALTHOUGH, to be accurate, the laying and repairing of ocean cables does not come within the sphere of this book, many readers will be interested in a few particulars of this work, which is so closely allied to the submarine branch of engineering.

Cables are laid and repaired by specially constructed vessels which have, in addition to huge "bunks" or holds for storing the heavy cable, special machinery for picking them up at sea when repairs are needed.

Cable ships are fitted with a large sheave, or pulley-wheel, at the bow and another at the stern, over which the cable can be either hauled in or let out.

When the object is the laying of a new cable, the vessel simply steams away from the shore station, to which one end of the cable is fixed, paying out the line behind her until eventually she arrives at the station on the opposite coast.

A curious story is told of the laying of a British cable-line from Tangiers (Morocco) to Gibraltar. The British Minister at the Sherreffien Court, after much difficulty and delay, succeeded in obtaining from the Sultan permission for the cable to be laid

from Tangiers; but when the cable ship arrived, and the news leaked out among the fanatical population of the city that a "magic ship" was approaching, alarm and excitement ran so high that the local authorities decided not to allow the cable to be landed until the matter had been again referred to the Sultan, with a notification of the alarm caused among the populace; and a messenger was despatched hot-foot to the capital. Realising that after all the Sultan might withdraw permission for the laying of the cable on hearing of the alarm and resentment among the people of Tangiers, it was decided by the British Minister and the Captain of the cable ship to effect the landing of the cable by a ruse. It was suggested to the Mussulman Governor that as the ship might "run away" and the Sultan be annoyed, it should be placed under arrest, and that this should be carried into effect by holding it to the shore with a strong rope.

The bazaars of Tangiers were ransacked without avail to find a long enough rope of sufficient strength for the purpose. Then the news was conveyed to the Governor that there was plenty of rope on the ship itself for this purpose, so the Governor, attended by an escort, proceeded on board, and the vessel was solemnly placed under arrest. When it came to the question of the rope for attaching the vessel to the shore, the captain appeared to reluctantly agree to use the huge cable stored in the bunks, and one end was duly conveyed on shore. The anxious fears of the fanatical

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THE CABLE STEAMER "ANGLIA" ASHORE ON THE COAST OF COUNTY DOWN, IRELAND

This unique illustration shows the large sheave or pulley-wheel projecting beyond the bow, over which cables can be hauled in or let out.

population were temporarily relieved; but, early the following morning, when they saw the arrested vessel slowly steaming to sea paying out the cable

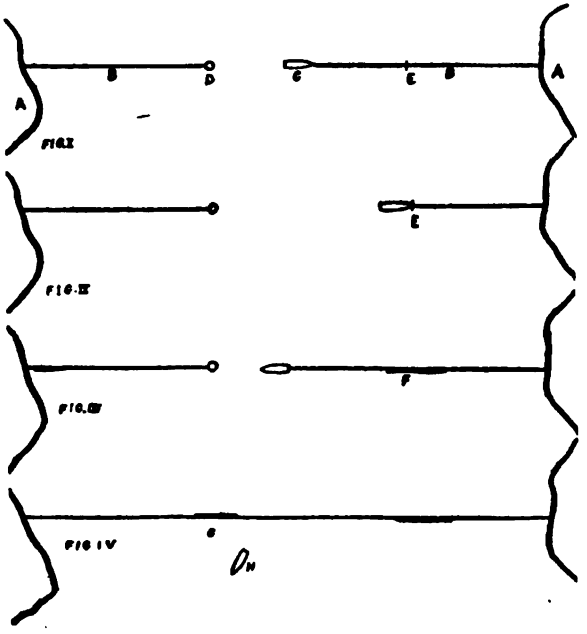

FIG. 46.—Method of Cable Repairing. *A*, *A* are the two coasts connected by the cable *B*, in which a "fault" has been proved to exist somewhere in section *E*. *C* is the cable ship, which is steaming along examining the cable after having cut it and buoyed the "sound end" *D*. II. The exact position of the fault is discovered by the cable ship. III. The damage is repaired by the introduction of a sound section *F*. IV. The two ends are rejoined at *G*, and the cable ship steams away.

behind, they watched her, and marvelled at the "magic" which could produce a cable without end, until she disappeared in the blue haze of distance.

The repairing of a submarine cable is, however,

the principal work of these ships. When a fault in a cable becomes apparent, the electrical engineers on shore can tell in which section the damage exists, and as the course of a cable is charted when it is laid, the whereabouts of the damaged section on the ocean bed can be approximately determined. The cable ship is then despatched to the spot, grapnels are lowered, and by allowing the vessel to drift slowly across the course, the cable is caught by the flukes or hooks of the grapnels, and hauled on board by powerful steam winches.

The cable is then cut and tested in each direction to see where the fault lies, the "sound end" being fixed to a buoy and lowered into the sea, while the other end is hauled in over the sheave in the bow as the vessel steams along until the actual damage is discovered. A new section of cable is then inserted, and the ship returns to the buoy holding up the "sound end," the two halves are rejoined, and the repaired cable dropped back into the sea-bed (see Fig. 46).

The Water Telescope

The catoptric tube, or water telescope, is an instrument which is used, as its name implies, for searching the sea-bed when the water is very clear for sponge, coral, pearl shell, or rocks. In strong tideways, or where the water is at all muddy, it is quite useless, but in the crystal waters which cover many of the pearling grounds, sponge-beds,

and coral islands, the sea-floor can be searched with this simple instrument even when the water is deep.

Its value to the submarine industries is considerable, for it enables new pearling grounds and sponge fisheries to be prospected for and located without continual descents by divers, although, of course, it does not in any way usurp the position of the latter, for when a "bed" is discovered by the catoptric tube, divers must be sent down to determine whether or not it is worth working upon.

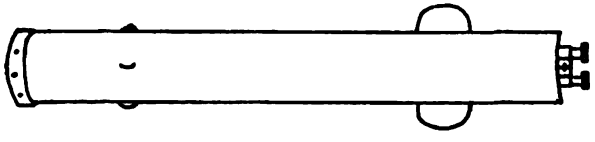

FIG. 47.—A catoptric tube.

In appearance this instrument is not unlike a very large telescope, as will be seen from Fig. 47, only without the *telescopic joints*, for a catoptric tube does not "shut up" like an ordinary telescope. In construction it is simply a tube of about 6 to 10 inches diameter, fitted at the lower end with a strong circular plate-glass, and lugs on the outside of the metal tubing to which ropes are attached for keeping the tube steady in the desired direction when under water. At the top or surface end are strong handles for convenience when holding the tube, but in some cases trunnions are supplied so as to fit into the ordinary rowlocks of a small boat. This latter method is decidedly the most convenient, for the hands of the operator are left free

to adjust the head-cloth, which is used, as with a camera, to shut out the light when looking through the powerful field-glasses which form the eye-pieces of the tube.

The water telescope is usually made in lengths of from 4 to 8 feet, so that it can be extended at will to any reasonable depths, but the object of this instrument is merely to penetrate the surface when the waves caused by the lightest breeze, floating weed, and even sea-dust, disturb and cloud the images beneath.

The utility of this simple little appliance—which, by the way, is easily constructed with some lengths of zinc tubing weighted at the lower end and a pair of field-glasses—is strictly limited to clear water and moderate depths. Even those whose interest in submarine matters is purely one of pleasure would find in the use of the catoptric tube a certain enjoyment, especially in waters where the sea-bed can be explored at considerable depths, such as around Bermuda and the West Indies, off the coasts of Virginia, Florida, California, and even at times and places on the North American Atlantic coasts and in the English Channel.

Diving Armour

The many different and often elaborate designs for diving-dresses, which would enable their wearers to descend to astounding depths, which have been designed during recent years, make it quite im-

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ONE OF THE MANY ATTEMPTS TO DESIGN AN EFFICIENT SUIT OF DIVING ARMOUR

possible to describe even a few of them here. Those of my readers who are interested will find voluminous information in just a few of the Patent Office publications on this subject.

Although the brains of many versatile inventors have been engaged in wrestling with the problem, nothing really practical has, so far as the author knows, yet been devised in the way of a really safe deep-sea diving-dress which would enable its wearer to descend and work at any depth up to, say, 500 feet. The problems which have to be overcome before a practical idea can be evolved are both many and complex; and the almost inconceivable pressure on every part, which at a depth of 500 feet would amount to 217½ lb. on the square inch, has to be guarded against, while at the same time the *armour* employed must be made flexible, so that the diver can move freely. Any form of dress which relies upon mechanical arms and legs is foredoomed to failure, for, even if reliable, its sphere of utility would necessarily be restricted to a few simple movements. Then, again, the difficulty of forcing air down to divers working at such a great depth, and of providing for the outlet of superfluous and respired air, appear to be almost insurmountable. The weight carried would also be so considerable that, when the diver was in shallow water, movement of any kind would be almost impossible. These are just a few of the many difficulties which surround the evolution of the ordinary diving-dress into deep-sea armour.

One of the most interesting and practical efforts to construct a dress of this description was made some years ago by Messrs. Buchanan & Gordon of Melbourne. This invention is made in two parts; the *upper* half, consisting of the helmet and body, is made entirely of stout copper, the arms and *lower* part of the dress (except the thigh, which is also of copper) consists of a series of special metallic springs covered with very strong waterproof material. The arms are also fitted with springs, and the legs with jointed supports, to prevent the pressure of water from forcing them upwards. There is, in addition, an arrangement by which the suit can be adjusted to the height of the wearer. The dress is fitted with two valves —the inlet, or air-supply valve, and the outlet, or escape valve—both of which are under the control of the diver. To the escape valve is attached a floating hose, the upper end of which can be submerged to any required depth below the surface, thus allowing the air to escape with greater facility, and enabling the diver to regulate the pressure.[1]

Although the practical utility of this invention is open to question, and very little use appears to have been made of it, there are many ingenious points which make it one of the most feasible of deep-sea diving-dresses.

[1] From the description given by Messrs. Siebe, Gorman & Co.

CHAPTER XX

"OXYLITHE" AND THE SUBMARINE ESCAPE DRESS

In an earlier chapter I described what is known as the pipeless diving-dress, which enables men to remain under water for a period of three hours without any connection by which air is passed down to them from the surface. We now come to a much simpler dress which weighs only a few pounds and can be donned in 20 seconds. Its use as a diving-dress for working purposes is, however, restricted to shallow water, although as a means of escape for the crews of submarine boats in the event of disaster, it can be used in any depth up to 150 feet providing the escape is effected within ten minutes.

Before entering upon a description of this dress and its method of use in submarine boat disasters, something must be said of the mysterious chemical compound called oxylithe which makes it possible of accomplishment. The importance of this newly-discovered substance is such that without it at least half a dozen of the most modern submarine appliances would be impracticable.

Oxylithe, the invention of a Frenchman, is a

greyish-white powder which, on coming in contact with water, gives off pure oxygen violently. Its discovery was brought about by a series of experiments commenced in 1897 with the object of solving the problem of respiration in submarine boats, and enabling the crews of these modern fighting ships to remain submerged for a very much longer period than was then possible.

For a long time chlorate of potash was the only practical resource for the manufacture of oxygen, and the gas was almost exclusively used in pharmaceutical laboratories, but in recent years its applications have developed considerably, thanks to the new processes of manufacture and particularly to the possibilities of preserving oxygen under pressure in steel bottles of limited volume, from which it is drawn off by simply turning on a tap.

If the appearance of tubes of compressed oxygen has marked a considerable progress, their manipulation, it must be admitted, presents a serious disadvantage, which consists in the difficulty experienced in transporting them from place to place, and it can easily be imagined that the use of bottled oxygen is in many cases impracticable.

The discovery of oxylithe, however, makes a still further advance in the production of oxygen gas, inasmuch that it is possible now to dispense with the heavy steel cylinders into which the ordinary oxygen of commerce has hitherto been compressed to very high pressures. Oxylithe is oxygen in a latent state, in a solid body that can be treated cold

By special permission

THE SUBMARINE ESCAPE-DRESS

The top view shows a man fully equipped, and the lower illustration emerging from the conning-tower of a submarine boat.

by the simple action of water, in the same way that acetylene gas is produced by the action of water on calcium carbide, but without any of the danger or objectionable smells which accompany the latter (except when the new dry process for generating acetylene is employed).

When water comes in contact with oxylithe, oxygen is immediately given off violently, but when the water is withdrawn the generating process stops at once. One pound of oxylithe powder will produce about 3 cubic feet of chemically pure oxygen; therefore a very large quantity of gas represents only a very small bulk in the solid.[1]

For use in submarine boats, deep mines, and for divers, firemen, sewermen, &c., as well as for numerous medical purposes such as the resuscitation of persons overcome by noxious gases or half drowned, it is almost impossible to overestimate its value.

Submarine Boat Disasters—A Means of Escape

Turning from the characteristics of oxylithe and the importance of its discovery, to one of the most recent uses to which it is put, we find it operating a life-saving appliance which has been designed to enable the crews of wrecked submarines to escape to the surface, and for use as a shallow water diving-dress. It can also be used as a smoke helmet.

[1] From information supplied by Messrs. Siebe, Gorman & Co.

The apparatus consists of a plain, thin helmet, provided with a front look-out glass, to which is attached a loose canvas jacket reaching to the waist. Inside the front of this jacket is a pocket containing a purifier and oxygen generator. These two chambers contain the oxylithe powder, which, when in contact with the damp vapour of the breath, gives off the requisite supply of oxygen for breathing and at the same time absorbs the carbonic acid gas of the respired air, thus enabling the wearer when submerged to breathe the same air, repurified, over and over again.

The helmet and jacket are made in one piece, thus insuring the whole dress being air-tight. The principle is similar to that of the diving-bell and the earliest pattern Siebe "open dress." When the diver enters the water the air inside the dress is compressed upwards, the pressure increasing the deeper the descent, the water rising inside the jacket to a corresponding extent. This, however, is so arranged that the water is never able to rise in the dress higher than the wearer's neck, thus allowing sufficient room for breathing even in comparatively deep water.

This apparatus, which is the joint invention of Captain S. S. Hall, R.N., and Staff-Surgeon Oswald Rees, R.N., is not only carried in the submarines, but is also used on the destroyers and torpedo-boats of the British navy.

It can be adapted with equal facility for use in mines, sewers, wells, or other places where there is

By permission of *Messrs. Siebe, Gorman & Co., Ltd.*

DONNING THE SUBMARINE ESCAPE DRESS

The operation takes only twenty seconds, and when on life can be supported in the dress for over two hours.

danger from noxious gases; conflagrations, when it is necessary in spite of the smoke to get at the seat of fire; in the foul bunkers and double bottoms of ships; or, as a shallow water diving-dress, to examine and repair ships' hulls, propellers, and valves.

In order to understand its use as an escape-dress in submarines it is necessary to refer in the first instance to a few points in connection with disasters to this type of vessel.

It is generally recognised that the principal danger to which submarines are exposed is collision, which was the cause of the loss of the British vessels "A 1" and "B 2" with their crews. As all submarines are now equipped with appliances such as compressed-air, electric, and hand-pumps for dealing with any small leakage which may occur, there remains for all practical purposes only one condition under which a submarine is likely to be unable to rise to the surface, namely, an inrush of water into the hull involving a large and sudden loss of buoyancy, such as would almost inevitably be caused by a collision when submerged.

Secondly, there must be borne in mind the danger which arises from the electric storage batteries, for when salt water gains access to these, poisonous gases are given off, and the crew, boxed up in the submarine, stand in great danger of suffocation. Thirdly, there is the problem of how to escape from the sinking submarine and ascend to the surface.

Let us examine the means at present provided in

nearly all British and many foreign submarines for overcoming these difficulties and dangers with the aid of the dress already described.

When packed in a submarine the whole dress

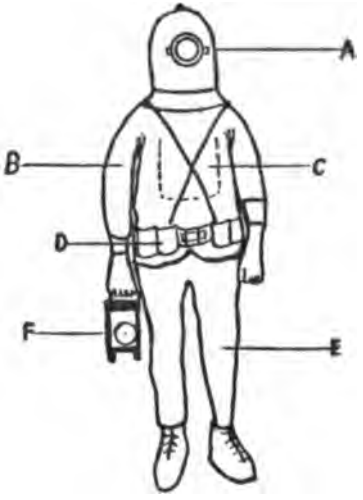


FIG. 48.—Sketch showing principal features of the submarine escape-dress. *A*. Canvas-covered helmet of light weight in which canvas jacket, *B*, is stored when not in use. *C*. Bag which can be inflated by the wearer to act as a life-buoy. *D*. Belt containing weights (only used when the dress is being employed as an ordinary shallow water diving-dress). *E*. Man's ordinary trousers or wool pants. *F*. Electric self-contained hand lamp.

only occupies a space of less than a cubic foot, and weighs from 13 to 16 lb., the canvas jacket, to which is attached the air-purifying appliance, being tucked away inside the helmet (as shown in the illustration above), thus giving it a great advantage over many cumbersome safety appliances, for both weight and space are strictly limited in a submarine.

The dress can be donned by each member of the crew in 20 seconds, and, when equipped in it, life can be supported under water or in the midst of the most poisonous gases for nearly two hours by means of the air-purifying apparatus containing the oxylithe.

It will be seen from this that should a collision or other accident occur involving the rapid filling with water of the submarine when below the surface, the crew have only to don this dress in order to maintain life until they can escape from the wreck. The third factor in the problem, viz. a means of escape from the submarine after the disaster, is at present provided for in modern boats by an "air-trap," which prevents the whole vessel from being filled with water.

If the hole caused by the collision is in the bottom of the submarine, the water cannot entirely fill it, as the air in the boat would be entrapped and compressed in the upper part of the vessel by the inrush of water. (The principle is the same as that of the diving-bell.) But it is more likely than not to be the case that the rent caused by the collision would be in the upper part of the vessel, and in order to provide for this contingency two steel partitions, extending downwards for several feet, are fixed to the roof on each side of the vessel. The spaces so encased form two "diving-bells," in at least one of which the air is entrapped even if the whole back of the submarine is torn open on one side. A clear understanding of this arrange-

ment in the interior of modern submarines will be obtained on referring to Figs. 49 and 50.

The air entrapped in these spaces, even when the submarine is full of water, will, however, not save the crew from suffocation for any length of

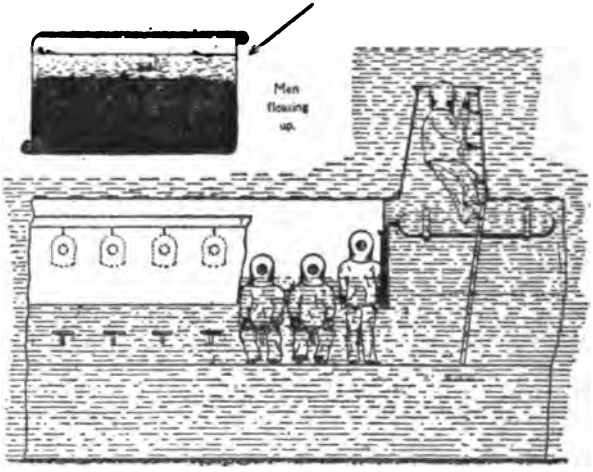


FIG. 49.—Longitudinal section of a wrecked submarine boat filled with water except for the spaces in which the air has been trapped by the partitions. Inside these traps the crew have donned their escape-dresses, and one is seen climbing out of the conning-tower in order to float to the surface. This diagram also shows the pipes supplying air from the boat's compressed-air cylinders to keep the water down to the lowest possible level in the traps.

time on account of the poisonous gases which are quickly generated, but they provide "breathing space" in which the men can make preparations for escape. One of the dresses already described being stowed here for each member of the crew, all they need do when the boat is filling with water is to stand in the trap and quickly don their dresses,

when the pressure of air in the helmet is automatically adjusted to that in the trap, which varies according to the depth to which the submarine sinks.

The arrangement of these air-traps is such that the water inside the dress cannot rise higher than

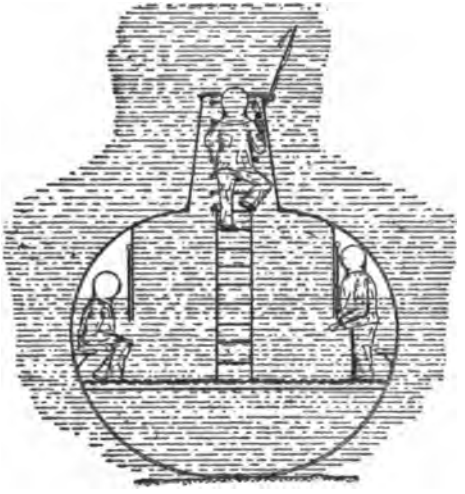


FIG. 50.—Transverse section, showing the air-traps and partitions.

the wearer's chin. When this takes place the crew, temporarily converted into divers, will possess a small positive buoyancy, owing to the air in their helmets, and, on coming out of the traps and opening a balanced hatch in the top of the submarine, will rise to the surface, slowly at first, but with an increasing amount of buoyancy as the pressure of water declines and the air space in the dress increases.

This, however, is not all, for on arriving on the surface it is possible for the wearer to inflate a double portion of his jacket by blowing down a tube, thus forming a kind of life-belt. This enables

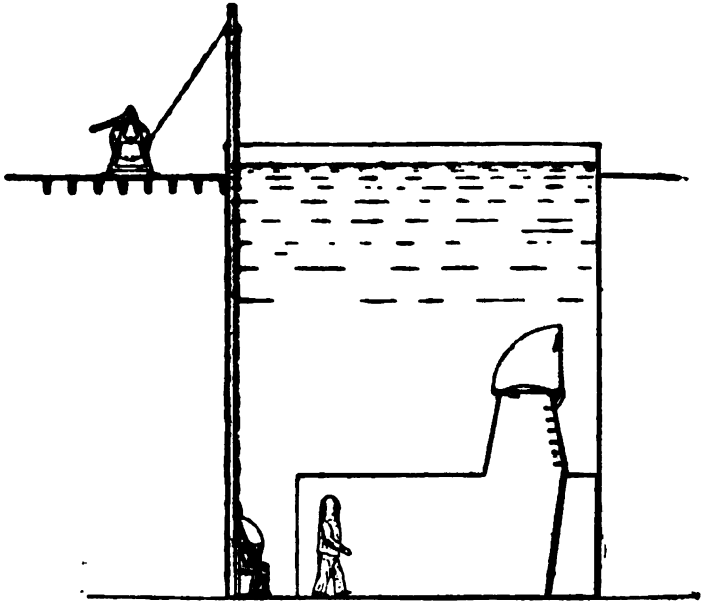


FIG. 51.—This diagram shows the method of training men in the use of the escape dress at H.M. Dockyard, Portsmouth. The man is lowered to the bottom of a tank while sitting in a chair, dressed, and with his head and shoulders in a miniature air-trap. On arrival at the bottom he leaves the trap and makes his way through an imitation submarine to the conning-tower, when he has to release the hatch and float to the surface.

him to open the port-hole, or window in the front of his helmet, and breathe the fresh air, a very necessary provision when one comes to consider that the air-supply stored in the dress is sufficient to last only two hours, and if the ultimate rescue on the surface should be delayed beyond this

period the crew might otherwise perish in sight of safety.

There are, however, one or two questionable points in connection with the safety appliances just enumerated, which will, no doubt, occur to many of my readers. One is the probability that in the event of a submarine being run into when submerged the shock of the collision would be so great that the vessel would be rolled almost over as well as cut into, and many of the crew either rendered unconscious or incapable of even the simplest action by the terrible shock and following chaos. For it does not need a very vivid imagination to picture the cramped interior of a submarine at the moment of impact with the sharp steel bows of a great liner travelling at full speed.

CHAPTER XXI

SUBMARINE BOATS—THE MYSTERIES EXPLAINED

THE submarine, which has opened a new era in naval construction and warfare, is to most people a complete mystery. Its whole being is surrounded with an impenetrable secrecy, which makes it the most attractive of all types of ships.

"How do they sink? What causes them to rise? Do they use electric or petrol engines? What does it feel like to go down in one?"—are samples of the questions so frequently asked by many whose interest has been aroused by the veil of secrecy which enshrouds these important units of modern navies. Yet, to those in the know, such questions as the above appear but simple and elementary in the extreme, for the complex problems and real secrets lie far deeper than in the mere diving and rising of these curious craft.

In the next few chapters I shall, with the aid of diagrams, describe the principal features common to all types of submarine craft, and, when some of *the mysteries* have been explained, give an account of an under-water cruise and mimic attack in a submarine torpedo-boat, which, needless to say,

will not quite respond to the fanciful ideas possessed by many people.

The mercantile submarine has, for all practical purposes, not yet been evolved, although its use in salvage operations has been frequently demonstrated in the United States, England, and France. It is to its value as a "daylight torpedo-boat" that the submarine of to-day owes its importance, for this type of craft can approach hostile warships even in the full light of day without the latter being aware of its presence, and then launch a torpedo at the most favourable moment, which, if successful, might well send to the bottom the largest battleship afloat. For this reason, submarine torpedo-boat flotillas have been added to the navies of all the great powers.

Although to France belongs the honour of being the first to adopt the submarine torpedo-boat as a vessel of war, it was an American inventor, Mr. John P. Holland, who designed the original from which the vessels in the British, United States, and many other navies have since been evolved. The perfection to which they have now been brought is, however, the result of the collective ingenuity of a small army of inventors, engineers, naval officers, and scientists, whose aim and ambition it has been to bring about the realisation of the fictitious *Nautilus*, that marvellous creation of Jules Verne.

The purpose, then, of the submarine is to dive

beneath the surface of the water and steal up close to hostile warships and discharge her torpedoes with quickness and accuracy. In order to do this she must, although remaining unobserved herself, be able to keep constantly in view her object of attack. This is done with the aid of *periscopes*, but before these instruments come into play the submarine has to sink beneath the surface.

It is quite unnecessary to say much about the shape and outward appearance of a submarine, for many of my readers will have seen one of these queer, fish-like boats, sliding rapidly through the water with only its "whale-back" and conning-tower showing above the surface; but in case there may be some to whom the submarine is quite unknown, its essential features are clearly shown in Fig. 52.

Method of Submergence

It may sound ridiculous, in face of the many accidents which have occurred, to say that one of the greatest difficulties is to make a submarine sink sufficiently quickly, and one of the easiest of operations to make her rise, and yet such is undeniably the case.

It will be readily understood that any delay in disappearing beneath the surface when attacking would be a great danger to a submarine in action. For example, a number of hostile torpedo-boat destroyers are scouring the sea in advance of a fleet, and are discovered at daybreak by the sub-

marines, which are waiting to attack the fleet behind, approaching at a speed of 30 knots an hour. A hurried dive beneath the surface is necessary if the waiting submarines would avoid detection, which

FIG. 52.—A modern submarine torpedo-boat (American type). *A*. Deck superstructure. *B*. Scuppers for filling superstructure. *C*. Safety-globe. *D*. External connections. *E*. Conning-tower (4-inch armour). *F*. Periscope. *G*. Periscope motor (for turning, &c.). *H*. Air cowls. *I*. Conning-tower cap (opening sideways). *J*. Mast stays. *K*. Mast (not part of service equipment). *L*. Torpedo-tube cap. *M*. Torpedo-tubes (twin), torpedoes in. *N*. Air-flask (for expelling torpedoes). *O*. Hydroplane engines. *X*. Double casing. *Y*. Spare torpedoes. *Z*. Petrol storage tanks (2). 1. Air flasks. 2. Centrifugal pumps. 3. Air-lock, with submarine escape dresses. 4. Commander's platform. 5. Ladders. 6. Depth and deflection indicator, registering submarine's deflection from horizontal. 7. Speed dials. 8. External globe telephone. 9. Petrol engines. 10. Electric engines. 11. Dynamo, for recharging batteries. 12. Petrol engines—exhaust.

would, in all probability, mean destruction by the quick-firing guns of the destroyers.

When a submarine is travelling on the surface she is in what is technically called the *light condition*, that is to say, with her water ballast tanks empty, but when it is required to sink her so that only the tiny platform, or deck, and conning-tower are above the surface, water is let into these ballast

tanks, and the additional weight causes her to sink into the sea until her *back* is almost flush with the surface—this is known as the *awash condition.*

It is not difficult to perceive that when travelling awash, a wave might at any moment roll along the tiny unprotected deck of the submarine, break over the mouth of the conning-tower, and descend like a waterspout into the interior. Were this to happen a terrible disaster might result, for it must be remembered that when travelling awash, a very little additional weight would cause the submarine to plunge beneath the surface. In order to obviate this risk it has become a rule that when proceeding with this small margin of buoyancy, the hatch covering the mouth of the conning-tower should be screwed down and the submarine hermetically closed, ready to sink.

To many it may appear strange that total submergence is not accomplished by letting still more water into the ballast tanks, but entirely with the aid of the propellers and rudders. A submarine has two, and sometimes three, pairs of rudders; one pair of ordinary vertical ones to guide her to port or starboard, and a horizontal pair to cause her to dive and rise. The arrangement of these rudders and two additional *fins*—frequently placed on each side of the fore part of the vessel to assist the diving and rising—is clearly shown in Figs. 53 and 54.

In order to make the submarine dive beneath the surface, the horizontal rudders are deflected when the boat is proceeding at full speed. The action

A UNITED STATES SUBMARINE TRAVELLING AWASH

This illustration shows in a remarkable way the danger of the awash run in the diving-trim condition. A wave or sudden swell might easily overwhelm the conning-tower and flood the interior of the submarine.

of the water against the rudders is such that the bows are forced down and the whole vessel slides under the surface. The principle is much the same as that of steering an ordinary surface vessel, where the force of the water against the rudder causes the vessel to swing to right or left.

From this it will be seen that a submarine is only held below the surface by the action of her rudders on the passing water; should the propellers driving her along cease to revolve and the vessel slow

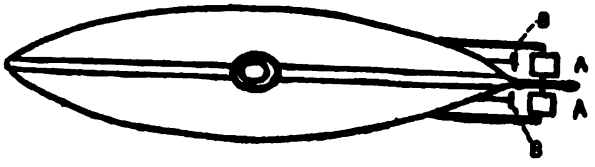


FIG. 53.—Plan of the exterior of a submarine boat, showing usual arrangement of (*A*) horizontal rudders (for diving and rising) and (*B*) twin-propellers.

down, she automatically rises to the surface because the rudders have no longer any effect.

Although the steering both on the vertical and horizontal plane is controlled by hand, it would be quite beyond the strength of a man to move the various rudders as required, so electric motors are installed to perform the actual work. In fact, almost everything in a submarine is operated by electricity.

In the earlier types of submarine boats a considerable time was required to open the valves and allow sufficient water to enter the ballast tanks to make them sink to the awash condition. Some

of the now obsolete French naval boats took as long as 15 to 20 minutes to carry out this simple operation. The main reason for this was, that they were designed with too much surface buoyancy, that is to say they rode too high in the water when floating in the light condition compared with the inadequate means then employed for the inlet of water into the ballast tanks, and were thus forced to let in an enormous quantity of water at a very

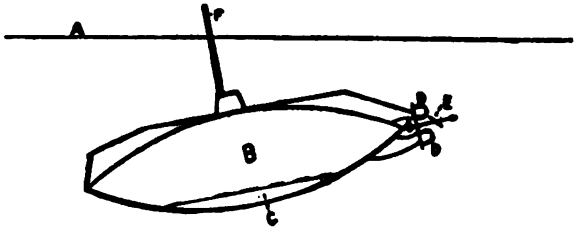


FIG. 54.—Diagrammatic sketch showing a submarine diving. *A*. Surface line. *B*. Submarine boat. *C*. Water in ballast-tanks. *D*. Vertical rudders. *E*. *Deflected* horizontal rudders. *F*. Periscopic tube.

slow rate before they settled down sufficiently to enable total submergence to be accomplished by the use of the horizontal fins and rudders. This great drawback has now been completely overcome, and the modern submarine can sink below the surface in about three minutes.

When water is pumped into the ballast tanks in order to make the submarine settle down, the air which normally fills these tanks is compressed into a fraction of its proper space, and is therefore always exerting a downward pressure which increases as more water is pumped in. Therefore, when it is

desired to bring the submarine to the surface again, all that is necessary is to open the valves and allow the compressed air to force the water out. It should, however, be remembered that there is really no need to "blow-out" the ballast tanks in order to bring the submarine to the surface, for this can be much quicker accomplished by simply elevating the horizontal rudders; but in this case the submarine only rises just above the surface—to the awash condition—whereas if the tanks are emptied of water she rises to the light or cruising condition. This substantiates the assertion made at the beginning of this chapter—that it is far more difficult to make a submarine sink than it is to make her rise.

Equilibrium

It has been said that a man walking from one end of a submarine to the other would in all probability cause her to plunge dangerously, so delicate is the state of equipoise when totally submerged. Whatever may have been the case in the early types it is certainly not so now. So steady are modern submarines when running below the surface, especially those of the British, United States, French, and German Navies, that the long up and down hill glides, which, with some boats, used to amount to *yaws* of from 20 to 30 feet, have now been reduced to a few feet in as many hundreds of yards. In fact this switch-back motion is almost unnoticeable except when the submarine is being

swung round at a sharp angle. In no case, however, is it sufficient materially to affect the firing of the torpedoes.

The reserve buoyancy of a submarine in the awash condition—or diving-trim as it is called in the British flotillas—is necessarily very small, amounting to little more than two or three pounds in a thousand, which in a 300-ton vessel means a difference of only about 100 gallons of sea-water between the ability to float and the inevitability of sinking. Any material increase in the small margin of what is known as *positive-buoyancy* must be accompanied by a corresponding increase in the power of propulsion, otherwise it would be quite impossible to drive her under, or, in other words, to overcome the vessel's natural tendency to float on the surface.

For these and other reasons, a submarine when running submerged is in such a delicate state of equipoise that any sudden increase or loss of weight would upset the balance and so cause the vessel to either dive or rise with dangerous rapidity.

This would be the effect produced when a torpedo was discharged were provision not made to counterbalance this sudden loss of weight by means of *compensating-tanks*, into which sufficient water is pumped to compensate for the loss of weight incurred by the discharge of *each* torpedo.

Many submarines are also fitted with bow and stern *trimming-tanks*, into which water can be pumped in such a manner as to correct any tendency

of the vessel to float too high or low at either extremity.

Propulsion

Of the many complicated problems surrounding submarine boat construction the motive power and propelling engines have been in the past, and are still, the most profound puzzles. Steam, compressed air, electricity, petrol, and heavy oil have all been used with varying results since first this type of vessel came into being; and many curious engines for using these *prime movers* in conjunction with each other and with chemical compounds have been evolved by ingenious inventors.

About steam and compressed air little need be said, for although given a good trial, especially by the French naval authorities, they were abandoned some years ago in favour of a combination of petrol and electric engines, which in turn have given place to more powerful machines using heavy oil and electricity.

The carrying of large quantities of petrol is under all circumstances attended with a certain amount of risk, and when many tons have to be carried in a confined space, as in a submarine, this risk is more than doubled, as the slightest leakage when the vessel is submerged would mean that a powerful explosive mixture of petrol and air would be made. It was to guard against this danger that white mice were carried in the earlier boats. Cages containing these animals were hung near

the arched roof of the submarine so that their delicate sense of smell and energetic squeaks at the first sign of poison in the atmosphere might serve as a timely warning of any escape of petrol.

It being also quite impossible, for obvious reasons, to use a petrol engine when running submerged, a second motive power, an engine, with its additional space and weight, has to be carried to drive the submarine when under water. For this purpose electricity is used in almost all types. But electricity, again, has many drawbacks. It costs in weight nearly thirty times more than other motive powers, and is extremely dangerous, for should salt water in any way gain access to the storage batteries, chlorine gas would be given off in large quantities, although in the more recent vessels of the British, American, and French Navies this danger has been minimised by enclosing the batteries in air-tight cases. On account of the weight and the space required, it is impossible to install a very powerful electric engine in a submarine (compared with the size of the boat), and thus both the speed and radius of action are curtailed.

If this division of power between the surface and submerged engines could be overcome, and the whole space made available for one powerful set of engines suitable for driving the vessel both on the surface and when submerged, not only would the mechanism of submarines be simplified, but a very considerable increase in both speed and range of action would naturally result.

In the "D" and "E" class British submarines, and in the more modern vessels of the American, French, and German Navies, heavy oil is being used in place of petrol on account of the increase in power obtained with greater safety.

Arrangements are made in almost all modern submarines so that when the vessel is using the oil engines for running on the surface the electricity for use when submerged is being made by a dynamo and stored in batteries. From this it will be seen that there are really three separate engines in a submarine: (1) the oil or petrol motor, which drives the vessel when on the surface, and, at the same time, by a suitable arrangement of gearing, operates a dynamo (2), which makes the electric current for storage; and (3) an electric engine which drives the vessel when submerged, obtaining the necessary power from the batteries.

It is, however, technically incorrect to say that there are two sources of power in a submarine, for electricity is not, in itself, a source of power, but merely a handy method of storing and transmitting it. The only actual source being the oil or petrol.

There are also numerous small engines to add to the complexity of machinery in a submarine, such as the air-compressors used for charging the torpedo-tubes with compressed air for expelling the torpedoes and for other purposes, and electric motors for operating the pumps, steering mechanism, and periscopes. In addition to all this, hand

mechanism is provided for use in case of a breakdown to operate most of these important appliances. Then again there is, of course, the armament mechanism for working the torpedo-tubes and semi-automatic quick-firing guns.

From the foregoing it may appear that the interior of a submarine presents a picture of mechanical complexity utterly incomprehensible. Yet such is not the case. The fanciful belief that the crew stand, boxed up in these vessels, sweating with the heat, struggling for breath, and with crank-shafts whirling uncomfortably close to the small of their backs, electric motors buzzing within a few inches of their ears, and nervous hands grasping one or other of the levers ranged in rows in front of them, is, doubtless, most romantic, but quite unreal. Much of the undoubtedly complicated machinery in a submarine is tucked away in the conical extremities, under the interior decking, and fixed to the arched steel sides. The centre is left almost entirely clear, so that trestle-tables may be erected for meals, hammocks swung for sleeping, and sufficient space allowed to make these small vessels as habitable as possible. Not the least difficulty of the submarine designer is to create order and leave space among the chaos of machinery which has to be installed in these peculiar and deadly little torpedo craft.

Vision when Submerged

Perhaps the greatest difficulty which has beset both submarine construction and navigation is the

puzzle how to see when submerged. This is now

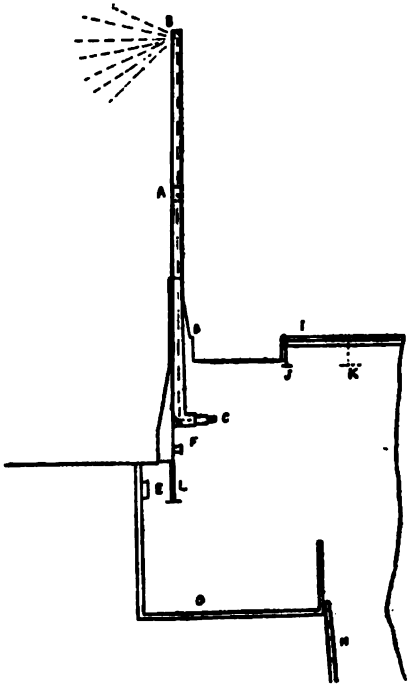


FIG. 55.—Diagram showing the "eye" of the submarine. *A*. Periscopic tube. *B*. Lens and mirrors reflecting views of surface down tube (dotted line). *C*. Eye-piece. *D*. Periscopic tube support or carriage to prevent vibration caused by water resistance. *E*. Row of indicators showing speed and depth of vessel below the surface, &c. *F*. Speaking-tube to engine room. *G*. Inside navigating platform. *H*. Ladder leading up to same. *I*. Conning-tower hatch. *J*. Wheels for screwing down same. *K*. Wheel for operating automatic release appliance for opening the conning-tower hatch quickly in case of emergency when using escape-dress. *L*. Wheel controlling electric appliance for turning periscope.

accomplished by means of periscopes, or tubes ex-

tending up from the roof of the submarine to a height of several feet above the surface—not unlike hollow masts. By a series of lenses and reflectors a picture of the surface is thrown down these tubes on to reflectors inside the submarine. A man with his eyes at the bottom of a periscope can see the surface clearly. Fig. 55 shows the working of this simple appliance. Although it projects above the surface when the whole submarine is submerged, it is too small an object to be easily seen moving through the water, and extremely difficult to hit by gun-fire.

The latest panoramic periscope—three of which are fitted in modern submarines—has a field of vision of about 60 degrees. The range of vision is, however, very short, owing to the periscopic tube projecting only a few feet above the surface. On a moderately smooth and fairly clear day steering by periscope is not altogether difficult, but at night or in fog this instrument is useless, and for this reason it would be almost impossible for a submarine to effect a submerged attack on an enemy at night. Hence the name given to this type of craft—daylight torpedo-boats—for in the brilliant light of day, when any attempt by ordinary torpedo craft to get sufficiently close to hostile warships to discharge a torpedo with reasonable hope of success would be foredoomed to failure, there is every possibility that submarines could effect a surprise attack.

Armament

The chief armament of all naval submarines is the torpedo, which is expelled by a blast of compressed air from one of the tubes fitted, in the case of the British and American boats, in the bow. Several torpedoes are usually carried by each boat, so that if one failed to strike the object of attack further attempts can be made.

About the efficiency of torpedoes nothing need be said here, for they now form an important weapon in every navy. The plan of a "Whitehead," which is the type used in most navies, and a brief description of its essential features may be seen on page 276.

The latest submarines built are also fitted with quick-firing guns for use when these vessels are cruising on the surface. The guns are arranged so that when it is desired to sink they can be made to disappear beneath the narrow deck of the submarine. The provision of guns has been made with the object of giving these vessels a means of defence should they be discovered by prowling hostile torpedo-boat destroyers or aerial craft.

Habitability

Many people imagine the interior of a submarine to resemble a stoke-hold, hot, stifling, and semi-dark, whereas the exact contrary is the truth. The

temperature is but little above the normal for a ship's engine-room, the air-supply is amply sufficient, and the whole interior is well illuminated by electric lamps.

The necessary supply of pure air is derived either from large steel cylinders containing the air in a highly compressed state or from flasks of oxylithe. The carbonic acid gas of the respired air being at the same time chemically absorbed.

Food is cooked for the crew by electricity, and drinking water obtained from special tanks. Notwithstanding these arrangements, however, it is almost impossible for the crew to live on board for many weeks at a time, owing to the small free space in the interior and to the cramped deck; but as the size and radius of action of these boats increase, so also does the space available for exercise, and thus the habitability.

Now that the reader is familiar not only with the principal causes of disaster to submarines, the safety appliances in use, and the general outlines and working of this type of vessel—and the so-called mysteries thereof are mysteries no longer—I propose describing a few of the most remarkable performances of various vessels belonging to the navies of some of the great Powers, but this must form the subject of a fresh chapter.

CHAPTER XXII

WHAT A SUBMARINE CAN DO

ALTHOUGH the latest British naval submarines, known as "E's," are big vessels compared with the earlier "A's," "B's," and "C's," the largest of which barely exceeded 300 tons displacement, they are but small when compared with the 1000-ton vessels building, and the *inevitable* submarine battleship of the near future.

The E's, which have a submerged displacement of 800 tons and a length and breadth of 180 feet and 23 feet respectively, are fitted with heavy oil engines of 1500 b.h.p., which gives them a speed of 16 knots on the surface, and, under the electric engines, 10 knots when submerged. As I pointed out in the previous chapter, the most important problem of the present moment is undoubtedly that of speed, for although great strides have been made in this direction during the past ten years, the speed of a submarine still falls far short of her natural enemy, the battleship. It is this drawback which often makes an attack by submarines on surface vessels steaming at full speed extremely difficult. The simplest description of this difficulty —known as the right-angle attack—is that of a

lame man walking up a street to throw a stone at a cyclist racing at right angles past the top end. The 1000-ton vessels of the British Navy have a speed slightly in excess of that of any of their predecessors. This gradual increase in the speed of submarines is, however, met by an equivalent increase in the speed of surface warships, from which it appears that nothing can be done in this direction until a new and more powerful engine or motive power suitable for submerged use has been devised.

The British E's are fitted with three periscopes, which enable the whole arc of the surface to be kept constantly in view when the vessel is travelling submerged. This not only minimises the risk of collision with surface vessels, but in time of war allows for the possibility, even probability, of one or perhaps two of these instruments—the "eyes of the submarine"—being rendered useless.

It will be readily understood that wide radius of action, or the ability of the submarine to proceed a long distance from a base and fight in the open sea, is a factor of great strategic importance. In this respect the strides made during recent years have indeed been rapid. It may be not without interest to give here some idea of the increase in the radius of action of British submarines since first this type of warship came into being as an integral part of England's first line of defence.

Class and Date.	Surface Radius.	Submerged Endurance.
A's. 1901–4 . .	500 miles.	3 hours full speed,
A's. 1904–5 . .	600 „	3 „ „
B's. 1905–7 . .	1500 „	4½ „ „
C's. 1907–10. .	2000 „	4½–5 „ „
D's. 1910–11. .	3500 „	5 „ „
E's. 1911–13. .	4000 „	7 „ „
Those built subsequently .	4500 „	.....

What this means will perhaps be more easily understood when it is pointed out that vessels of the E class can, if required, go from Portsmouth to Gibraltar, cruise quietly about for several days, fight an action, and return to Portsmouth, without going near a parent vessel or base to take in oil fuel or supplies of any kind.[1] Every sea and coast within 1000 miles of England's naval bases is thus accessible to immediate attack by submarines without attendant surface warships. Being able to travel submerged for five hours at full speed without rising to the surface even for a "breath of air" makes it possible and comparatively easy to cross the English Channel keeping hidden beneath the waves for the whole voyage.

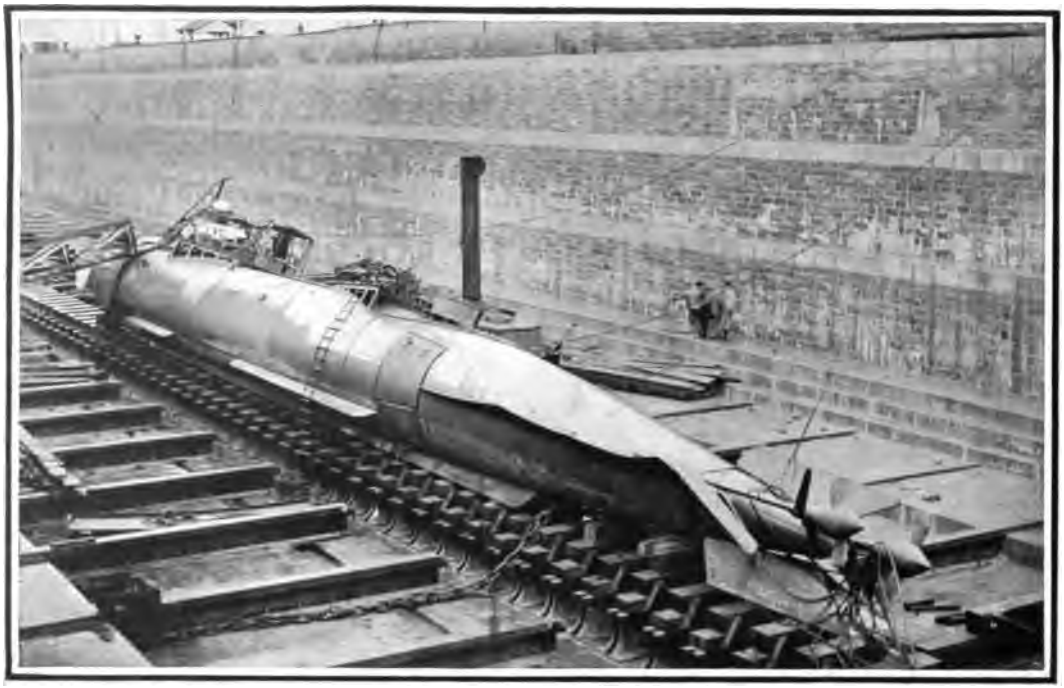
The armament of six Whitehead torpedoes enables these boats to chance "long shots" which were distinctly inadvisable when only two of these weapons were carried. The automatic loading and discharging devices, which are jealously guarded naval secrets, enable two torpedoes to be fired in

[1] About 15 tons of oil being carried.

less than five minutes. The operation requires opening the cap at the mouth of the submerged expulsion tube, discharging the torpedo already in the tube, closing the cap, blowing the water out of the tube, opening the breech, automatically moving the second torpedo into the tube, closing the breech, re-opening the cap, and discharging the second torpedo. It will be realised that for this to be accomplished in the short space of five minutes with delicate weapons weighing 1300 lb. each, not only great skill but also mechanical perfection is required.

The torpedoes themselves have been so improved with the advent of their new ally that they can now rip through a mile of water after being discharged from the tube in but little over one minute, and the explosive charge (200 lb. of wet gun-cotton) is amply sufficient to blow open a hole as big as the front of a small house in the unprotected hull—below the water-line—of a big battleship.

The provision of quick-firing high-angle guns in the British, American, French, and German boats, which are so placed that they can be automatically lowered out of the way into cavities of the deck with wonderful rapidity when it is desired to dive, has given to these vessels a weapon of defence against their determined enemies the torpedo-boat destroyer and the air-scout. Small as these guns are (12-pounder quick-firing), they are capable of doing considerable damage at moderate ranges, and



THE WRECKED FRENCH SUBMARINE "FARFADET" LYING IN DRY-DOCK AT BIZERTA

This view, which shows the vessel after salvage, gives an excellent idea of the superstructure and the rudder mechanism. The disaster to the "Farfadet" occurred through the submarine diving with one of her hatches insecurely closed. The entire crew were lost.

the rapidity and accuracy with which they can be fired even at high angles (sky-firing) makes them of great utility against air-craft.

Turning to the question of safety, we find all recent additions to the British and American flotillas provided with escape-dresses, air-traps, and a fair amount of reserve buoyancy. In addition, however, a hatch is now fitted inside the base of the conning-tower, so that if this projecting portion of the submarine is damaged by collision, as was the case with the ill-fated British "A 1," this base-hatch can be immediately closed and an inrush of water prevented. The upper hatches, or conning-tower caps, now open sideways instead of "athwart-ships" as in the older boats. This arrangement prevents their becoming jammed or forced open by the action of the water; on the contrary, the tendency would now be for the hatch to close.

The conning-tower and exposed portions of the deck are clad with 4-inch armour-plate to protect the vulnerable points from machine-gun fire. The angle of diving and rising is regulated by an automatic appliance, and a crusher-gauge is also fitted which prevents the vessel's submergence to depths where the pressure of water would be more than the steel sides of the submarine could stand.

The navigation of these under-water fighting ships is provided for in the same way as surface vessels, by compass, chart, and sextant. When travelling submerged, the distance below the surface can be seen at any moment by glancing at the

depth-gauge. The speed, the amount of oil remaining, the stored electricity for the submerged engine, the reserve compressed-air for breathing and discharging torpedoes, the temperature, the amount of water in the ballast-tanks, and, in fact, every condition of importance, is shown continually in the faces of the dials and gauges.

When travelling on the surface, communication with the shore, other submarines, or units of the fleet is maintained by wireless telegraphy from a temporary mast fitted above the conning-tower.

The United States naval submarines are almost identical with those of Great Britain, therefore little further need be said. Springing from the *original* stock, and being constantly enlarged and improved by a staff of clever and watchful designers and inventors, it could not well be otherwise. The latest vessels to take their place in the United States flotillas have the following dimensions: displacement, 500 tons; length, 160 feet; breadth, 13 feet; surface engines, 1500 horse-power.[1] They can travel on the surface at a speed of 20 knots, and when submerged at 12 knots. Their radius of action is about 2000 miles, and 6 torpedoes are carried.

The French submarines are quite as large and powerful as the British, having a submerged displacement of 1000 tons, and engines of 2000 indicated horse-power. Their length is about 240 feet, and their beam 20 feet. Their maximum trial speed

[1] Approximate.

was 20 knots on the surface and 10 knots when submerged. They have a very wide radius of action, and carry 7 torpedoes.

The German boats, although somewhat smaller than the British, French, and American, are by no means inferior in comparative fighting qualities.

CHAPTER XXIII

SOME CURIOUS PERFORMANCES BY SUBMARINES

ALTHOUGH submarines have long since passed the actual experimental stage, and are now capable of doing almost everything that will be required of them in open sea warfare, it may be of interest to give here a few of the most important tests—now matters of history—through which various designs of this type of war-craft have passed on the road to perfection.

The only time a submarine boat has ever succeeded in sinking a battleship in actual warfare was during the American Civil War, when the *David*, a small wooden vessel driven by hand-power, attacked and sank the Federal warship *Hausatonic* off Charleston, Virginia. In the many naval engagements which have taken place since this historic event submarines have played no part. For many years submarine navigation was looked upon in much the same incredulous and pessimistic manner as was aviation ten years ago. The few who believed it possible of accomplishment, and did not hesitate to express their opinions were received with smiles of derision, while those who brought

forward inventions were looked upon as "cranks." But France led the way and America followed, while England watched. Other countries, like Italy, Norway, and Spain dabbled in it half-heartedly, but no real progress was made until the first French naval submarine, the *Gymnôte*, was launched in 1888.

For ten years France continued to experiment, during which time three vessels were built by the Government and several by the inventors themselves. Then an American inventor, Mr. Holland, who had been experimenting for many years, succeeded in inducing the United States Navy Department to enter the field with a boat designed by himself, which was built at Elizabeth Port, New Jersey, in 1897. This vessel was the forerunner of many submarines of the same type acquired for the navies of several of the great Powers.

The first trial of importance carried out by the French authorities took place between Toulon and Marseilles with the second French submarine, named *Gustave Zédé* (I), in the spring of 1899. An account of the attack made by this vessel on the warship *Magenta*, which appeared in the French papers, may be given here in the words of M. Lockroy, the Minister of Marine: "The eyes of all on board were fixed on the sea. Officers and men stood watching the crest of the waves, and every minute there were exclamations as some one fancied that he had seen the submarine. We imagined we saw it everywhere, but it was nowhere.

It was, in fact, proceeding quietly and invisibly towards its prey. The excitement of the crew was at fever heat at the thought of the tortures which the bravest men, the most self-possessed commanders, would suffer in the event of a real attack by this unseen enemy. Suddenly a precise observation was made. The cupola of the *Gustave Zédé* had just appeared 400 yards away, still abreast of us, notwithstanding the distance which we had covered. Immediately orders were issued. The guns were brought to bear upon her, and the quick-firers depressed. The submarine had disappeared. She was hidden from our view and shielded from fire. A minute elapsed. Though orders were given to the engineers to put on steam, and the *Magenta* had gone some considerable distance in the sixty seconds, the admiral and myself, leaning over the bridge, saw approaching us with lightning speed a narrow white streak of foam. It was all that could be seen of the submerged torpedo of the *Gustave Zédé*, which struck the ship about 4 yards below the water-line. If it had been charged, the *Magenta* would have been sunk."

It was this historic sham fight between a submarine and a battleship which induced the French Ministry of Marine to continue the experiments which they had started ten years before.

As this work is not concerned with the history of submarine navigation, we can skip over the period of many years during which France and America continued to experiment with this type of craft.

It is sufficient to say that the first submarine built for the British Navy (from the designs of Mr. J. P. Holland) was launched in 1901. Italy and Russia, both of which had carried out experiments previously, followed a few months later, but Germany waited till 1904.

We now come to some of the tests applied to what may be termed "modern submarines." During the summer of 1905 the French vessel, *Cigogne*, successfully accomplished an experimental dive of 100 feet off Toulon. The submarine was kept at this depth for 15 minutes, and after coming to the surface, plunged again to a depth of over 60 feet, and travelled at this level for a considerable distance. The "Z," also belonging to France, dived twice in rapid succession to a depth of 72 feet, and another vessel reached the great depth of 130 feet in the following year.

These are but a few examples of the severe tests carried out with many French submarines, nor was America one whit behind in conducting experiments. In 1907 a submarine designed by Captain Simon Lake made a record dive of 135 feet. The account of this wonderful feat, which appeared the following day in the *New York Herald*, is of such interest that I am tempted to give it here, together with a description, from the same paper, of a 24 hours' continuous submergence by the Lake boat and its rival, the Holland submarine *Octopus*, which afterwards took its place in the United States Navy.

"*Newport, R. I., Thursday.*—Dropping 5 feet deeper in the water than any submarine laden with human beings has ever gone, the *Lake*, which has been competing with the *Octopus* in the trials before a Navy Board here, this afternoon made a new record for deep plunging in her class. She went down 135 feet. The world's record previous to this was 130 feet, made by a French submarine. The *Lake's* pressure gauge at 125 feet showed 52 lb. to the square inch.

"The requirement in the Naval Department specifications for the deep-sea test was 200 feet, but Captain Lake, after contemplating dropping his boat to that depth off Little Gull Island, in the Race, gave up the idea and decided to submerge her with the crew aboard in the deepest bit in the bay. This was found at the north end of the measured mile course, and there the *Lake*, its tender, and the *Nina*, with the Trial Board, and several other craft assembled about eleven o'clock this morning. After a half hour of sounding the desired depth was found, and the *Lake* was sealed up in preparation for the drop. The measuring tape and a pressure gauge was attached, and at the side of the submerging submarine, in a rowboat, were Naval Constructor Taylor, Lieutenant Commander William S. Smith, and Captain Simon Lake, the inventor. In the submarine were Constructor Edward Peacock and F. W. Baker, of Bridgeport, members of the company; Captain George Evans, commanding the boat; J. K. L.

Meads and John Mahan, of Baltimore; Edward G. Gallagher, of Boston; Samuel Ferguson, of New York, and Frank Spoer, of Brooklyn, members of the crew.

"The boat having been sealed up, began to submerge as water was taken into her tanks. The process was slow at first, and it was seven minutes and fifteen seconds before her conning-tower disappeared. Then submergence was quicker, and from the time the *Lake* was 30 feet beneath the surface, the measuring tape in the hands of Mr. Taylor ran out so fast that it was easily seen that the boat was sinking with increasing rapidity. From the submergence of 30 feet till the *Lake* reached the bottom it was only three minutes and forty-five seconds. The crew could very clearly feel when she bumped the bottom, and Captain Evans immediately gave orders to blow out the tanks preparatory to going up. This was an anxious moment for those on board, for the question of whether or not they were to ascend was to be settled in the next instant almost. Just as expected, however, the boat's buoying mechanism began to do its work, and in nine seconds, seemingly with a bound, the boat began to rise. Mr. Taylor, who still had the tape, said she came up so fast that he could measure the degrees and note the time. She was, in fact, up in one minute and twenty-six seconds, during which she discharged 3 tons of water. In all it required the boat nineteen minutes and eighteen seconds from

the time she was sealed to sink to the bottom, and altogether the boat was sealed about twenty minutes and forty-eight seconds.

"Immediately the conning-tower hatches were opened, and a hurried examination showed that no water had leaked into the *Lake*, which was verified in a more careful examination that was made later. The boat's machinery had also escaped damage, for under power of her gas-engines she ran a mile into her slip at the torpedo station. While the submergence of the *Lake* this morning will not meet the specification, it will be taken for what it is worth by the Trial Board.

"The twenty-five per cent. model of the Burger subsurface boat, with which its owners are making a bid for part of the navy appropriation for submarine and subsurface boats, was given a trial by the Board this morning. She made three runs over the measured-mile course in the bay, the first at a rate of 8.93 knots, the second at a rate of 8.59 knots, and the third at a rate of 9 knots, the mean being 8.78 knots. The boat is only 35 feet on the water-line, and is driven by a 28 horse-power gasoline engine, which makes her performance quite remarkable."

"*Newport, R. I., Thursday.*—Up from the bottom of the bay came the submarine boats *Octopus* and *Lake* late this afternoon, after their twenty-four hours' continuous submergence test. One by one the twenty-three men on board filed

out of the conning-tower, none looking any the worse for his experience. Indeed, every countenance to a man was wreathed in smiles, and as evidence that the air which they had been breathing was reasonably pure, every face bore a flush of health and every eye was as bright and as keen as ever.

"It was the close of the long comparative habitability test of the two boats as prescribed by the Navy Department. Incidentally new records of sustained life under the sea had been made, the seventeen hours for which a party on the submarine boat *Fulton* was submerged at New Suffolk, L. I., in the spring of 1902, having been the previous record. Later in 1902 a party lived twelve hours on the *Fulton* submerged at the torpedo station.

"As the effect on the air in a submarine is a much more important detail of such a test than the matters of comfort and facilities for cooking and sleeping, the Board hurried aboard each boat as soon as it came up to get a sniff of the atmosphere, and to note conditions in a general way.

"All through the night and day periodical communication with both boats was kept up, the submarine signal being used in the case of the *Octopus*, and the direct telephone furnishing a means of speaking with those on the *Lake*.

Telephoned to Deep

"The telephone system by which the *Lake* connected herself with the shore was an ingenious

device. As soon as she was submerged a buoy was cast off, to which there was attached a telephone wire passing through a hose. The receiving instrument and transmitter were also attached to the buoy and protected by a copper covering. The buoy, which is part of the superstructure of the submarine, was released by a lever worked from within the boat. The whole contrivance, when cast off, was picked up in a boat and taken on board the tender *Vesta*.

"A little after three o'clock, Captain Marix sent forward orders for the *Octopus* to come up at half-past three. Her forward tanks were blown out first, and then the after tanks were relieved of their great weight of water. No means were taken to make a record at rising, and so the black monster slowly belched forth her water and arose. Captain Marix, Captain Walling, Lieutenant-Commander Smith, and Naval-Constructor Taylor were already alongside in a small boat, when at twenty-three minutes to four the hatch over the conning-tower slowly moved upwards and Captain Cable appeared.

"'Good afternoon,' he said, as he stood up and looked around. Then there came forth one by one the members of his crew. They looked very much as they did when they went down the narrow way into the bowels of the boat twenty-four hours before. The Board made a hasty examination of the boat, and came up to prepare for the rising of

the *Lake*. It was then raining hard, and the members of the Board, floating about in a small boat, had a really uncomfortable experience.

"Regarding his journey to the bottom, and his long rest there, Captain Cable said but little. He said that he had used about one forty-fourth of the stored air in his boat, from which he estimated that so far as air was concerned, he could have remained below for three days longer. He said they ate and slept below just about as they would have done had they been in their homes.

"Then over the under-water telephone Captain Lake was ordered to bring the *Lake* up at four o'clock, but he misunderstood, and it was thirteen minutes later before she began to blow out her tanks. Captain Lake did not come out at once, but waited below for the Board, which went down as soon as the opening of the conning-tower hatch made entrance possible.

"Later, Captain Lake said: 'We could easily have remained submerged for another twenty-four hours. We used a comparatively small supply of compressed air—in fact, not more than 200 lb., and this was not applied until near the end of the test. If we had used oxone, of which we had plenty on board, and if we had been allowed to open our diving-door to admit water to the diving-compartment, with which to force the carbonic acid gas, we would have drawn very little, if at all, upon our supply of compressed air. With all the *Lake's*

various air-disposing arrangements in use, a crew in the boat could easily stand a submergence of three days.'

"The scientific results of the interesting experiments will not be reduced to figures for several days. A sample of the air in each boat was taken in a bottle at stated periods, and this will be examined for carbonic acid gas and chlorine gas, which are very noxious, and may have been gene-

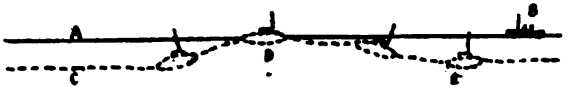


FIG. 56.—Sketch showing manœuvre known as the "porpoise dive." *A*. Surface line. *B*. Object of submarine attack. *C*. Course of submarine boat. *D*. Obtaining a momentary view of the whole surface enabling the exact direction and distance of the "enemy" to be ascertained. *E*. Sinking again to approach within torpedo range.

rated during the four hours the engines were under way."

About the experiments undertaken by British submarines little can be said, for directly a submarine is commissioned her experimental stage is considered to be practically past, and except for a few minor trials the naval crew have their whole time to practise for war. Of course the British vessels are constantly exercised in travelling submerged, "porpoise diving" &c., but erratic dives to great depths are not considered, in British naval circles, to be of any value, either as a practice or as an experiment, for in time of war deep plunges

would never be required, and the vessel which could sink to a depth of 300 feet would in all probability be less efficient as a fighting machine than the lighter-made boat which could only go down to 50 feet.

CHAPTER XXIV

SALVING BY SUBMARINE BOAT

ALTHOUGH salvage operations have, up to the present, nearly always been carried out in one or other of the ways described in earlier chapters it has many times been suggested that submarine boats could advantageously be employed for this purpose, and one well-known American inventor—Captain Simon Lake—has constructed several submarines capable of performing some wonderful salvage feats.

These vessels, unlike ordinary submarine boats, are capable of travelling not only *on* and *under* the surface, but also *along the sea-bed*, for which purpose the hull is mounted on four wheels. Reference to Fig. 57 will enable the reader better to understand the principal features of these craft.

Sinking from the surface to the sea-bed is accomplished in a very ingenious manner. The weights (*R*) are lowered on to the bottom by steel-wire hawsers unwound from power-reels (*S*). Water is next allowed to enter the ballast tanks (*N*), until the vessel's remaining buoyancy is less than the weights dropped; or in other words, sufficient water is allowed to enter the tanks to cause her to sink sufficiently to be hauled down by the power-driven

reels winding in the hawsers connecting the weights, (see Fig. 59).

When the vessel is, by this means, hauled down until her four wheels rest on the sea-bed, the weights are drawn into cavities in the keel, and the vessel becomes a submarine motor-car, able to roll along the sea-bed in any direction.

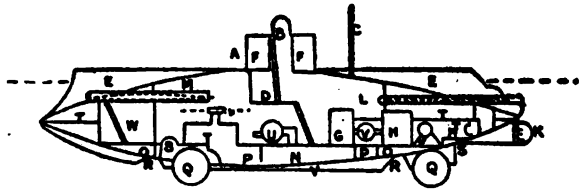


FIG. 57.—This diagram shows a Lake type of submersible fitted up as a submarine torpedo boat. (Used in the Russian Navy.) *A*. Armoured conning-tower. *B*. Look-out cowl. *C*. Optical tube. *D*. Navigating platform. *E*. Superstructure. *F*. Petrol tank. *G*. Petrol motors (2). *H*. Electric motors (2). *I*. Storage batteries. *J*. Propeller shaft. *K*. Vertical rudder. *L*. Stern torpedo tube. *M*. Pair bow tubes. *N*. Main ballast tank. *O*. Torpedo compensating tanks. *P*. Trimming tanks. *Q*. Wheels. *R*. Drop-weights. *S*. Power reels. *T*. Hydroplanes and mechanism for operating same and steering engines. *U*. Centrifugal pump. *V*. Dynamo. *W*. Diving chamber. *Y*. Keel, which may also be released.

It might be supposed that the wheels would sink into the soft sand or shingle forming the bed of the ocean in many parts, but this, however, is not the case, for the weight of the vessel, or pressure of the wheels on the bottom, can be increased or diminished as required. For instance, in the muddy hollows of rivers the pressure may be as light as 100 lb., while on the hard sand of the

sea-bed, where the currents are strong and it is necessary to "sit tight" in order to prevent the vessel being washed out of its course, the weight may be increased to over 1500 lb. This is accomplished by simply admitting more water into the ballast tanks or pumping some out.

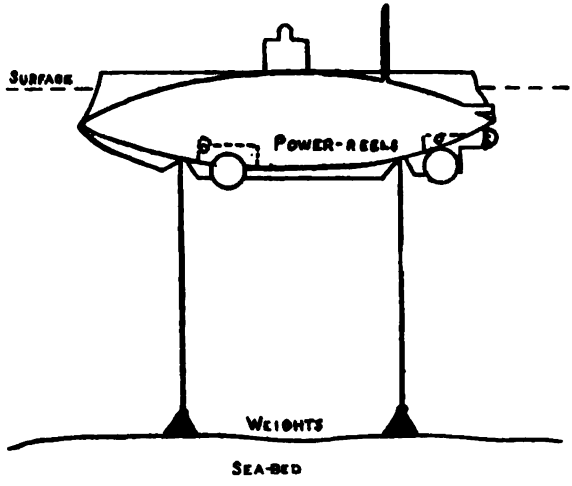


FIG. 58.—Lake submersible ready to be hauled down on to the sea-bed.

The vessel is propelled when on the surface by a gasoline engine which not only operates the screw but also the dynamo for re-charging the batteries and the air-compressor. The electric motors, which are used when the vessel is running submerged, can either be switched on to work the propellers or the driving wheels; while the batteries not only supply the current for these engines but also for operating the power-reels for lowering and hoisting

the weights, and the derrick machinery for use in submarine salvage operations.

In the *Argonaut*, an early type of Lake submarine, a plentiful supply of air for all purposes was drawn down from the surface. Her two masts being hollow, one was used as an exhaust pipe for the gasoline engine, which was employed both on

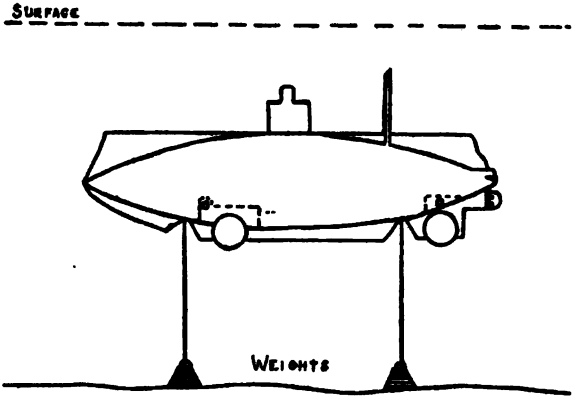


FIG. 59.—This shows the submersible being hauled down by her power-reels.

the surface and when the vessel was submerged, and the other for drawing air down into the boat (see Fig. 60). But in the latest types this somewhat primitive method of obtaining the necessary air-supply has been superseded by the more modern method of carrying down in the vessel flasks of compressed air, purifying chemicals, and using electricity instead of the more dangerous petrol for a submerged motive power.

A means by which divers are able to leave the

vessel when submerged and work on the sea-bed is provided. This ingenious arrangement consists of a compartment into which the diver and his assistants go, closing the watertight door behind them. Compressed air is then admitted into the chamber until the pressure of air inside equals the pressure of the outside water, which, as I have already pointed out in previous chapters, varies according to the depth. The trap-door in the

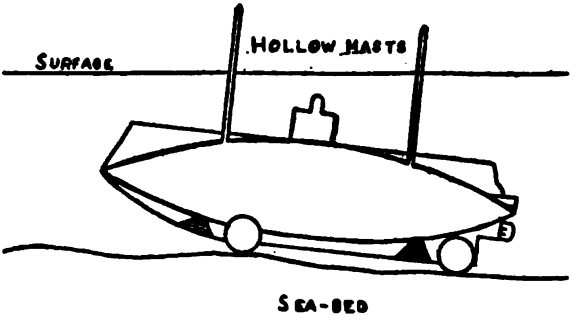


FIG. 60.—Lake boat *Argonaut* travelling on the sea-bed, with hollow masts supplying air from the surface.

bottom, giving access to the sea-bed, can then be opened without any possibility of water entering the chamber, as the air contained equals that of the surrounding water, and thus forms an invisible barrier. The diver, equipped in any of the dresses previously described, and supplied with air either from a pump being operated inside the chamber or from a compressed air supply, is then at perfect liberty to leave the vessel and work on the sea-bed, carrying on salvage operations with the aid of the derrick fitted on the submarine, the laying

or destroying of mines, the recovery of pearl shells, sponges, torpedoes, or treasure, and the repairing of cables.

In describing a two months' cruise in his experimental boat *Argonaut*, during which time over 1000 miles were covered on and under the surface, Captain Simon Lake makes the following interesting observations regarding the sea and river beds which they explored: "We have been cruising on the bottom in rivers, in Chesapeake Bay, and beneath the broad Atlantic. In the rivers we invariably found a muddy bed; in the bay we found bottoms of various kinds, in some places so soft that our divers would sink up to their knees, while in other places the ground would be hard, and at one place we ran across a bottom which was composed of a loose gravel, resembling shelled corn; but in the ocean, however, was found the ideal submarine course, consisting of a fine, grey sand, almost as hard as a macadamised road, and very level and uniform."[1]

It must not be supposed, however, that these wonderful vessels are capable of crawling along the sea-bed in any depth of water, for, needless to say, there are depths in which the pressure would be so great that the sides of almost any vessel, no matter how strongly built, would be crushed in like an egg-shell. But in any reasonable depth of water, travelling in this way is almost as safe as on the surface. Rocky places are negotiated by

[1] Fyfe's *Submarine Warfare*, published by Grant Richards.

lightening the vessel so that she floats over without touching the bottom, in the same manner as any ordinary submarine, while rising can be accomplished either by blowing out the water in the ballast-tanks, releasing the weights, or, in an emergency, by releasing the heavy keel. By this triple method of coming to the surface absolute safety is assured, for should one apparatus fail, it is highly improbable that the other two would do so at the same moment.

For salvage purposes a special suction-pump is provided. At a demonstration of the working of this appliance, when the submarine was resting on the sea-bed, several tons of coal were sent up to a barge on the surface from the hold of a sunken wreck, and, according to a New York paper, it was transferred at the rate of a ton a minute!

Captain Simon Lake has designed and constructed many submarine boats, some of which have taken their place in European navies.

The number of submarine salvage ships which have been invented, and the absolute impracticability of many, make it both impossible and unnecessary to give any further information here, for notwithstanding the many really ingenious and practical vessels which have been evolved, almost all the salvage work now undertaken is carried out by surface vessels and independent divers.

One remarkable vessel of this kind was designed with the specific object of crawling along under the

ice of the Polar Sea, in order that the then undiscovered poles might be reached! Another equally ridiculous and impossible vessel was *carefully planned* for taking passengers across the Atlantic under water; the charge per head for this enjoyable trip was not stated, possibly the assignment of a life policy was *le prix de billet* in the promoter's mind. Nevertheless there have been a few really clever and practicable inventions in this field, one, of quite recent times, being intended for the pearling industry on the Australian coasts, and having mechanical arms for collecting the shell in very deep water, where the pressure would be far too great for the ordinary diver.

Salving by means of submarine boats has, however, not yet come within the range of practical engineering—although its day cannot be far distant

CHAPTER XXV

IN THE CONNING-TOWER OF A SUBMARINE TORPEDO-BOAT[1]

ALTHOUGH of little value from an engineering or scientific point of view, it may be of interest to some of my readers to give here some "first impressions" of an under-water cruise and sham fight in a submarine torpedo-boat, gained some years ago, when submarine navigation was in its infancy, and I began to take an interest in this type of craft possessing such wide and fascinating possibilities.

It was a gusty day, and the tide was running swiftly as we stepped from the quay of a small French seaport on to the tiny platform which is all there is of deck on a submarine. A squall came whirling towards us across the gloomy water!

Quite up to date was this submarine, and one could not help admiring her inventor and commander as he stood in the "look-out," just in front of the conning-tower, his face strong, keen, and alert as he watched the levers and indicators ranged in front of him. Below the conning-tower and right in the centre of the boat were the tanks of petrol and compressed air. A submarine is one mass of intricate machinery.

[1] By kind permission of the *London Evening News*.

We burrowed into the interior of the vessel, to find the same complexity. Easy enough to sink, but how difficult to raise! We returned to the conning-tower, over which, when the boat should sink, a steel cap would tightly close.

The indicator bell rang. At last the dial hand pointed to "Full speed ahead." The wind whistled shrilly. . . .

Sinking

In the conning-tower we sat on chairs of basket-work slung from the semicircular steel roof. We were at the mouth of the harbour now, gazing through thick glass port-holes at endless white-crested waves. A breaker, larger than the rest, washed over the back of the vessel and broke against the conning-tower in a shower of spray. For a moment we could see nothing—could only wait.

The captain was peering through a port, specially constructed so as to keep clear of spray. Suddenly he bent forward, his eyes shining. He pulled one of the brass levers. There came a quick, hissing roar as the water rushed into the ballast tanks. An indicator marked the quantity taken in, and then—then we could feel a strange, heavy, water-logged motion coming over the boat. Now the surface of the sea was on a level with our eyes. The boat gave a little lurch forward. The rushing noise ceased. There came absolute, mysterious quiet. There came a downward, gliding sensation.

The interior of the boat was plunged into darkness a blackness to be felt. We could feel rather than hear the throbbing of the great, steady electric motor. Silence—we were below the sea. Never shall I forget that first moment, that sensation of absolute deadness and isolation, of being for ever cut off from light and life.

As the room was flooded with electric light the sensation passed. The captain, who was grasping a small brass wheel, said in a voice that echoed in that circular steel hull:

"I am now going to give you an idea of what submarine warfare would be like, by discharging an 18-inch Whitehead torpedo from the bow tube. But first I will bring the boat up with a porpoise dive to get a view of the surface, as we should do in time of war to ascertain the position of the enemy."

In a moment we could somehow feel that the boat was travelling at a slight upward angle. Through the port-hole we could see that the water was changing colour, from black to dark green, from dark green to light green—and then in a flash the whole surface came into view, the sun shining on dancing waves, and in the distance the dark hull of a large ship outlined against the sky.

The Torpedo

Down again to fifteen feet, gradually creeping closer to our imaginary foe, the vessel we had just

caught sight of in the distance. Looking over a small white table, on which the picture of the surface was cast by the optic tube, the minutes seemed to pass like hours. Then the hand of the commander, which had been resting nervously on one of the indicators, was sharply drawn forward. An instant's suspense—and nothing but an ominous click as the torpedo sped from its tube.

Imagine the suspense of those moments in warfare! With us, of course, the "war-head," or front part of the torpedo which carries the explosive and the apparatus for firing it, had been replaced by a dummy.

The atmosphere began to grow hotter and hotter as we once more sank to lower depths. The air became more and more vitiated, and at last we were gasping for breath. Suppose at this depth anything should go wrong?

The captain quietly smiled across at us and advised us not to try to take long breaths, but to breathe quickly. At once we felt relief, and at last began to get accustomed to what we had at first held to be bad air, but which was really air artificially made and poured into the room for our consumption. I looked at my watch and found we had been under the water for nearly two hours and a half.

Then at last came the signal, the tilt and quick rush upwards once more, the changing colour of the water as we gazed at it through the portholes, the flash of the surface line across our eyes!

The sky, the sparkling sea, light, sunshine, the world of life as opposed to that silent mysterious world of darkness below! The man-hole was thrown open. A wave of fresh air rushed in upon us. The wind was ecstasy.

And yet—we had been below that surface! And, as with the explorer in the Arctic regions, so with us, the impression of that under-firmament of dark water was upon us, its silence and its glamour!

CHAPTER XXVI

SUBMARINE EXPLOSIVE MINES

ONE of the most important factors in the science of submarine warfare is the explosive mine, which is used both for the attack and defence of harbours, rivers, and narrow waterways. The system of defence consists of the mooring of these mines in such positions as to make it impossible for hostile ships to pass without either striking or coming within the destructive zone of one or more of them. The system of attack is to *countermine*, or to place hostile mines in the defenders' field and destroy it by their explosion.

The mines themselves are of two kinds, one is designed to explode on being struck by a passing vessel, and is known as a *contact mine*, and the other is fired by an electric current from the shore, and is called an *observation mine*. The explosive mostly used is gun-cotton, owing to the safety with which it can be stored, manipulated, and even used in a wet state. Another important advantage of gun-cotton over various other explosives is that it seldom explodes in sympathy with surrounding mines, but requires to be actually fired. The importance of this will be better realised when it is pointed out that it is frequently necessary in warfare

to explode certain mines over which hostile ships are endeavouring to pass while leaving others near by intact, ready to repel a second invasion or to blow up ships in closer proximity to them. The actual explosion is caused by the detonation of fulminate of mercury in conjunction with small priming charges of dry gun-cotton. The fuses con-

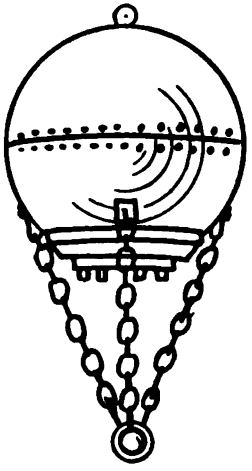


FIG. 61.—Spherical buoyant contact mine.

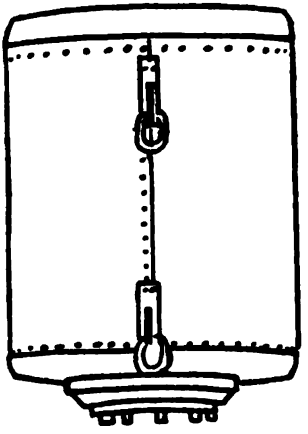
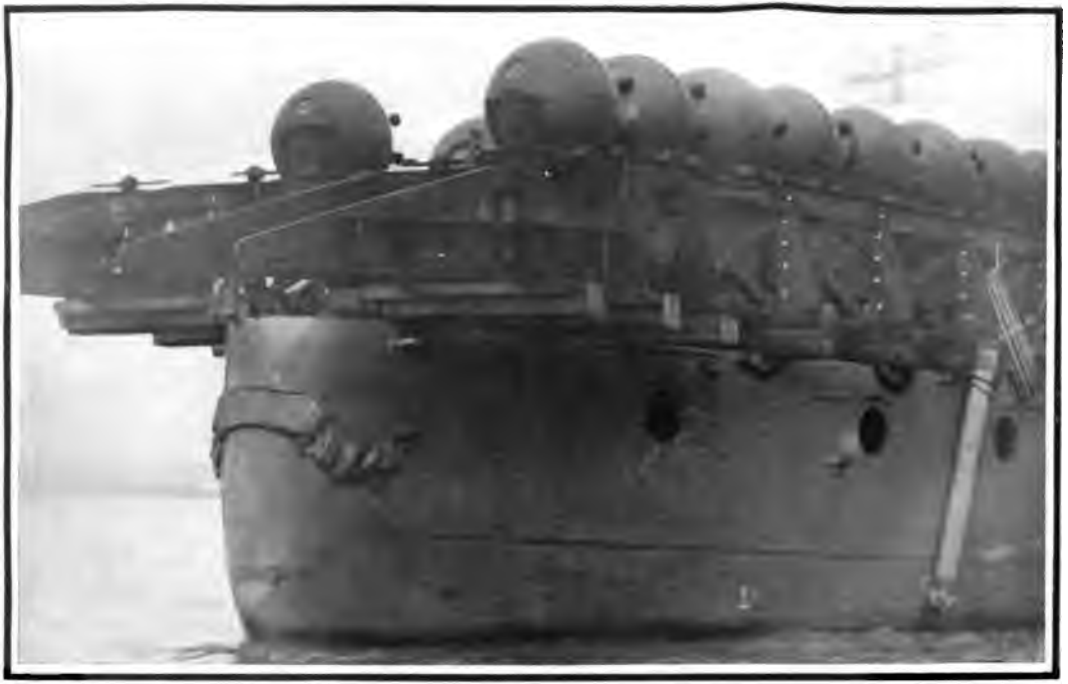


FIG. 62.—Cylindrical buoyant contact mine.

taining the fulminate of mercury are fired by electricity either from the shore or from a battery in the mine itself. Occasionally, however, a series of mines are connected to a battery in a boat, or on the sea-bed in the centre of the line of defence.

The shape and size of mines naturally varies according to requirements. The two most usual forms are, however, the *spherical* and *cylindrical* (see Figs. 61 and 62). The former has been found



From a photo by *Stephen Cribb, Southsea*

A MINE-LAYING SHIP

Stern view of a British naval mine-laying vessel. The spherical mines, ranged in a double row on the rails which project over the water, can be automatically dropped in a string as the vessel steams along. In this way a mine-field can be very quickly laid.

by experiment to be able to withstand the most external pressure, and also to offer the least resistance to strong currents, hence they are the more reliable for defensive purposes, as they are less likely to be affected by the explosion of countermines. The casing of these huge submarine bombs is mostly constructed of mild steel.

There are two different types of both contact and observation mines; one is made to float level with the surface and is called *buoyant*, and the other is fixed on to the sea-bed and is known as a *ground mine*. To enable a clear understanding to be obtained of the various types of mines used in modern naval war, it is necessary to refer to the diagrams. A small spherical buoyant mine suitable for the destruction of small craft, such as torpedo-boats and submarines, is shown in Fig. 61. Its charge consists of 50 lb. of gun-cotton, but if it is sunk beneath the surface to be used as a ground mine, this charge is increased to 250 lb. The spherical case shown in Fig. 63 is made to contain a much heavier charge. When intended as a buoyant mine it contains about 100 lb. of explosive, but to make it suitable for submerged use the inside of the case is heavily lined with cement and the charge increased to 500 lb. of gun-cotton. This is the ideal harbour defender, it being capable of seriously damaging even the largest warship at fairly close range, which would almost certainly be the case in a narrow harbour entrance. If, however, the channel to be defended is a broad one, a

line of mines can be laid across it in two or four sections, leaving a narrow zigzag passage through which friendly shipping can be piloted.

In deep water, where a mine is required to fire

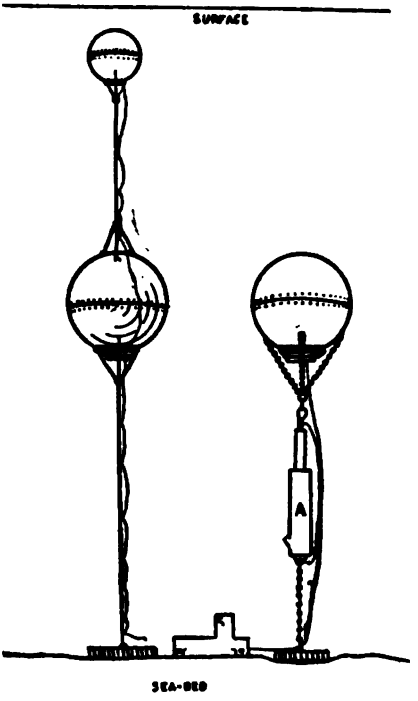


FIG. 63.—A large buoyant contact mine with striker above moored in deep water.
A permanent secret mine (for description, see text).

on contact, it is moored some little distance below the surface (see Fig. 63). Above it, and near enough to the surface to be struck by passing vessels, is the little spherical bulb containing the electric circuit-closer, which on being struck, fires

From a photo by *Stephen Cribb, Southsea*

MINE-SWEEPING GEAR ON A TRAWLER

Since the Russo-Japanese War demonstrated the effectiveness of submarine mines several innovations for the laying and destroying of these weapons have been made in the British Navy. Among them is a flotilla of trawlers fitted on each side with the gear shown in the above illustration. By sweeping along the bottom of the sea the mines are lifted up into a kind of shute or slung mat. These small vessels would, in time of war, be used to clear away the mines laid by the enemy.

the huge mine beneath. This is the type most frequently used for closing broad waterways.

When it is desired to maintain a more or less permanent mine defence in a narrow waterway, buoyant mines are kept moored close down to

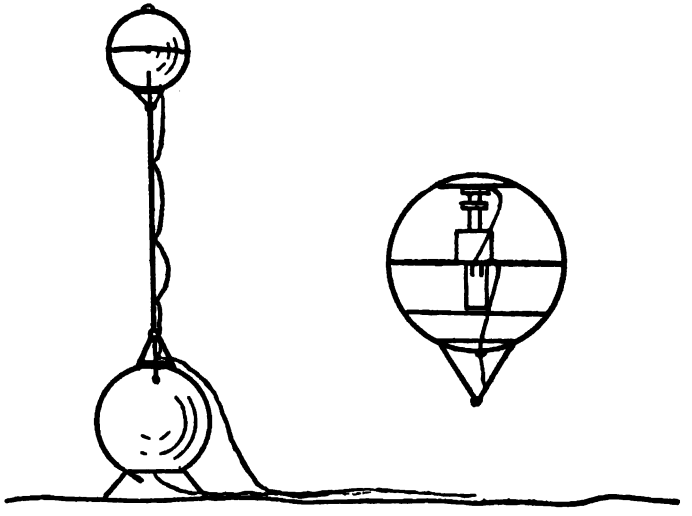


FIG. 64.—A spherical ground contact mine. The "striker" will be seen above, floating near the surface.

A small spherical buoyant contact mine. This diagram shows the electrical arrangements causing the mine to explode on being struck by a passing vessel.

their sinkers on the sea-bed, so that in time of peace their positions may be unknown, and they may remain free from injury by friendly shipping. This type of mine, shown in Fig. 63 (B), is arranged so that when an attack is expected it can be made to rise within a few feet of the surface. The mine is held down by a gripping-box *A*, inside which is a small explosive charge. When it is desired

to cause the mine to rise, this small charge is fired by electricity from the shore, the link holding the mine down is severed, and it rises to the full extent of the mooring rope.

Clearing a channel through an enemy's submarine mine defences is usually accomplished by counter-mining, which consists of dropping automatically ten or twelve mines in a series from a special launch of high speed in the waters actually mined

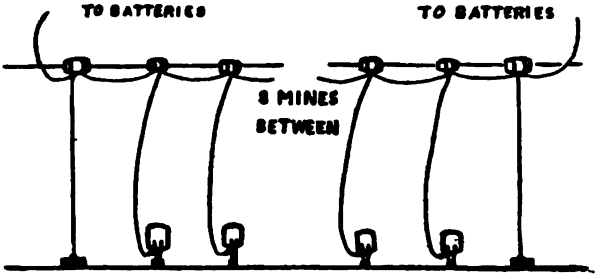


FIG. 65.—A line of counter-mines.

by the enemy. This is done so that when the counter-mines are fired they destroy the carefully prepared submarine bombs of the enemy. This dangerous and difficult manœuvre is usually carried out for the purpose of clearing a safe passage through the enemy's mine defences for the attacking fleet. The mines employed for this work are usually cylindrical. Their charge is a heavy one, being mostly 500 lb. of gun-cotton. They are arranged in groups of from six to twelve, and each series is fired from a battery by the simple twist of a handle.

Submarine Explosive Mines

Two innovations made by the British Admiralty, since the Russo-Japanese War proved beyond question the efficacy of submarine mines as weapons of defence, may be mentioned here. One is the "Special Mine-Laying Ship," and the other the "Mine-Sweeping Trawler," both of which are shown among the illustrations.

The mine-layers are really small obsolete warships converted into these new units of a fleet "in being." Two deep parallel rails, which project over the stern, are fixed on to the deck, and on these rest powerful spherical mines ranged in a double row. The releasing mechanism is so arranged that, as the vessel steams along, these mines are dropped automatically into the sea in a series. In this way a mine-field of wide area is very expeditiously laid.

For clearing away mines dropped by an enemy the British Navy has a flotilla of subsidiary trawlers. Each vessel would, in time of war, be fitted on both sides with a curious contrivance known as the "picking-up gear." This apparatus is lowered into the water, and "picks up" any mines which may lie in the path of an oncoming fleet.

Mining and counter-mining have played an important part in almost every naval war during the past half century. It forms one of the chief methods of harbour defence, and even small powers who cannot afford a navy usually provide their seaports with elaborate submarine mine defences.

CHAPTER XXVII

THE LIFE OF A TORPEDO

On no weapons of warfare are so much care and attention bestowed to keep them in a state of perfect order as those big steel cigars, torpedoes. The reason why is not far to seek. The latest design of torpedo costs several hundred pounds, and it is possible at some of the big works to make them at the rate of two a day. A first-class battleship takes the best part of three years to build, and may cost anything from a million upwards. This ponderous ship of war can be sent to the bottom of the sea in but a few minutes if struck by a torpedo.

The modern torpedo varies in length from 14 feet to 19 feet, and weighs up to half a ton. It has an extreme range of 4000 yards. The blunt nose, or "war-head" as it is called, is the business end of the torpedo, and contains the dry and wet gun-cotton and the fulminate of mercury necessary for the explosion. Behind the explosive head is the air chamber to hold the compressed air by which motive power is furnished. Then we come to the search chamber, or "brain" of the weapon, which contains most marvellous mechanism for directing and controlling the machine. Next comes the

engine-room, and, at the tail of the torpedo, the buoyancy chamber.

A torpedo, directly it is ready to leave the works, is packed in a thick wooden packing-case and despatched to one of the naval torpedo depots, the largest of which (in England) is at Portsmouth, where many hundreds of these deadly weapons are stored. The moment it passes into official hands it is treated with almost as much care as a promising race-horse training for a big event. On reaching the depot it is minutely examined and overhauled by the staff of experts. It is adjusted, oiled, and then the whole torpedo is covered with a thin layer of grease. If it has not previously been appointed to any particular ship, it is carefully placed in a rack and marked with its pattern number. As soon, however, as the torpedo is supplied to a vessel it is looked upon for ever as a part of the ship, and there will end its days.

The moment a torpedo is used for practice a new phase of its life begins. Like a boy first going to school, a record is started of its conduct. It has already been given a distinctive number, and at the top of each record, or "history sheet" as they are more often called, this will be entered. Below is entered the number of times it has been fired, and any eccentricities which have been noticed during its progress through the water. It is a curious fact that no two torpedoes have ever been constructed exactly similar. Each one is always found to have some little peculiarities when travelling through the

water. One will turn slightly to the left, another to the right, or sink in the water lower than is usual.

Every one of these little peculiarities indulged in by the torpedo are noted in the history sheet, and referred to before the weapon is again fired. By this means all the slight defects can be allowed for, and a much more accurate aim obtained. It is the

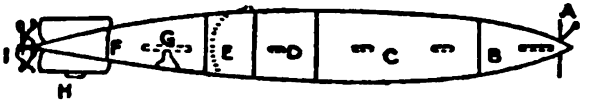
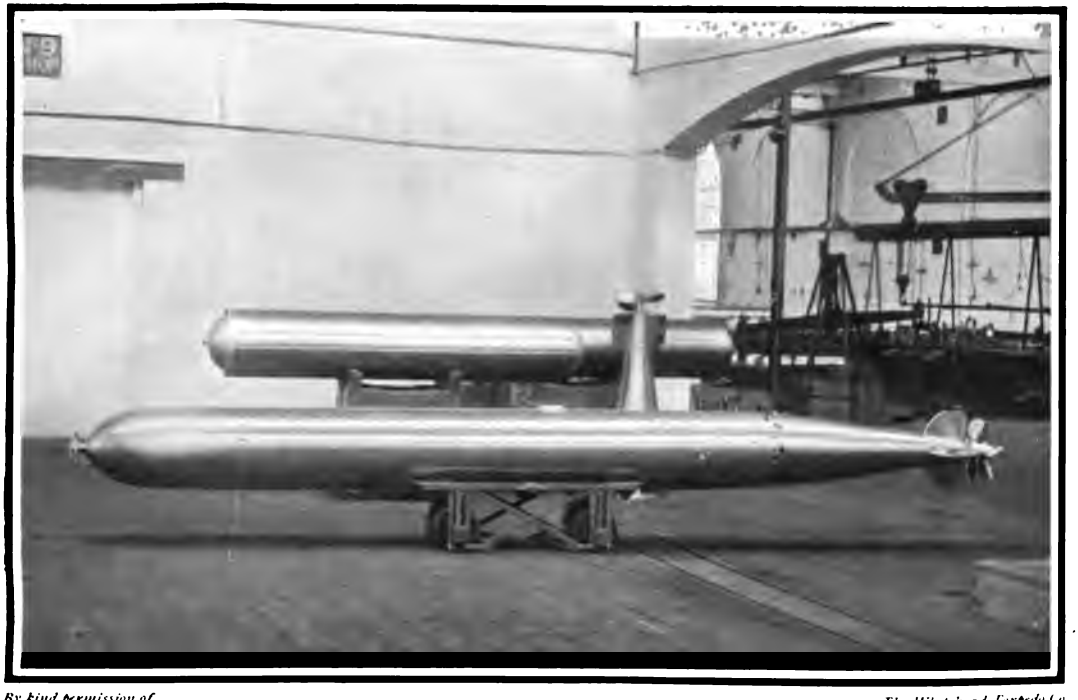


FIG. 66.—Sketch showing the essential parts of a Whitehead torpedo. *A*. Pistol, detonator, primer, which causes the explosion of "B" when the torpedo strikes an object. *B*. Explosive head, filled with wet gun-cotton. (The "war-head" is substituted by a weighty dummy during practice.) *C*. Air chamber with compressed air, at a pressure of approximately 1350 lb. per square inch, for action. The chamber is tested to stand a pressure of 1700 lb. per square inch. *D*. Balance chamber, containing mechanism for regulating the depth of submergence at which the torpedo is adjusted to run. *E*. Engine-room, containing propelling machinery (I.H.P. 60 in latest 18-in. type). *F*. Buoyancy chamber—a practically empty chamber—to give the necessary buoyancy to the torpedo. *G*. Gyroscope. An instrument for correcting any deviation of the torpedo from the line of fire. *H*. Rudders, and mechanism for operating. *I*. Twin-screws, operating "clockwise" and "anti-clockwise."

duty of the torpedo lieutenant to make up all the "history sheets" on a vessel, and he may be almost looked upon as a schoolmaster with a lot of small children to understand and manage. At any time when torpedoes are being fired he directs operations, and is held responsible for all the many little tricks his deadly pupils play him. In times of war, when each mistake may mean victory for the enemy—apart from the fact that several hundred pounds sterling falls to the bottom of the sea, wasted—his



By kind permission of *The Whitehead Torpedo Co.*

A MODERN WHITEHEAD TORPEDO

This illustration shows the identical torpedo which maintained the high speed of 42 knots for 1000 yards; the weapon being fitted with a special air-heating device which greatly increases the power of the compressed-air engines

position is an unenviable one. Sometimes, but not often, during trials a torpedo is lost even after a search has been carefully made, and the unfortunate vessel which fired the missing "Whitehead" returns home discomfited. Perhaps days afterwards the truant turns up, either washed ashore or towed in by some fishermen after having torn their nets to pieces.

Most parts of a torpedo are numbered, so that in case of any portion of the delicate mechanism becoming worn or broken the damaged portion may be returned to the depot, and a duplicate part immediately supplied.

Of the few real secrets which the navy jealously guards, the method of firing Whitehead torpedoes is one of the most important. But before explaining, as far as we may, how the engine of destruction is started on its deadly errand, let us look to the working of the torpedo itself.

A small chamber in the torpedo carries compressed air weighing about 9 stone. This helps to sink it to the required depth after it has entered the water. This air, escaping from the chamber by means of a regulating valve, drives the engine at a high rate of speed, which is almost uniform throughout the trip from the tube to the target.[1] The engines turn two screw-propellers at the tail of the torpedo; these revolve on the same axis, but in

[1] A special air-heating device is now used to increase the air-expansion and thus the power of the engine and the speed of the torpedo.

opposite directions, the object being to give stability to the weapon—a necessary thing inasmuch as it has no keel, and would rotate if it were driven by a single screw. The steering is effected by vertical rudders, which keep the torpedo in the required direction, while the proper depth in the water—usually from 10 feet to 14 feet—is maintained by horizontal rudders. The torpedo is kept submerged by means of the balance chamber, and is controlled in its steering by the wonderful instrument known as the gyroscope.

So marvellous is its mechanism that in favourable circumstances a torpedo, well aimed, may be depended upon to strike within a yard or two of the spot aimed at. Briefly described, the gyroscope is a rotating wheel which automatically controls the torpedo's course.

The method of firing a torpedo is very much like that of discharging a gun. It is expelled from a torpedo-tube by compressed air. Upon reaching the water the torpedo is driven by its screws in the required direction. The missile is guided by a very ingenious invention called a "torpedo director." This is a little brass instrument fitted with "sights" like a gun. When the sights are aligned on the enemy the officer in charge presses a key, and electricity causes the discharge.

Nearly every ship in the British navy is fitted with tubes and carries Whitehead torpedoes. There are two kinds of tubes, above-water and submerged. The latter are much safer to work

with, and have been found more effective, the above-water type being very liable to be struck just as a torpedo is being discharged.

Officers and men of the torpedo service in our own navy are specially selected for their nerve and resource, and receive special pay while on duty. They are all young, and mostly dare-devils; and such, indeed, they need to be, for the nature of the work they have to do. The game is a desperate one, for the mere suspicion of the presence of a torpedo-boat is enough to call forth a hail of shot from quick-firing guns. As the ordinary torpedo craft are practically unarmed, and their hulls are mere skins of steel stretched over light framework, it is impossible for them to resist even the shot of small guns, and two or three missiles going through a boat will ensure her destruction.

It is delicate work throughout, and requires delicate handling; and much will be expected of the torpedo, and the gallant men behind it, if Britain ever has to defend her position of "Ruler of the Waves."

CHAPTER XXVIII

A SUBMARINE WORKSHOP AND ITS CURIOUS MUSEUM

HARD by the Thames at Westminster are the offices and works of what is, perhaps, the most interesting of all the great engineering firms in the metropolis of the Empire. It is not so much the size of Messrs. Siebe, Gorman & Co.'s establishment—although large—which makes it remarkable, but rather the wonderful appliances manufactured for submarine exploration, construction, and warfare; the company of veteran divers talking of past achievements and adventures while awaiting the summons to further action, and the curious museum of relics from the deep, which makes these somewhat exclusive works of curious fascination and interest.

About the works themselves it is sufficient to say that almost everything pertaining to submarine work is made by this firm, which prides itself, not unnaturally, on the fact that no accident has ever occurred attributable in any way to faulty construction of apparatus supplied. About the curious submarine museum, however, a few facts may be of more than ordinary interest, as it is, I believe, the only one of its kind in the world.

The first to strike the eye is a motley group of relics from H.M.S. *Royal George*, the flagship of Admiral Kempenfeldt, which sank at Spithead in 1782. This ill-fated vessel had been lightened and tilted so as to expose a portion of her heavy oaken walls usually beneath the water, when, by the shifting of her guns, she suddenly heeled over and went down, carrying with her over 800 men, including the famous admiral whose flag fluttered from her mast. During the salvage operations, which extended over the six summers of 1839–1844, the following relics among others were recovered by the divers.

This group consists of a silver dish, spoon, and portions of a sword, from Admiral Kempenfeldt's cabin; a clay pipe, silver shoe-buckle, silk neckerchief, pistol, wine bottle with oyster-shells attached to it, a china cup, small shot, copper rivets, medal, the sole of a shoe, and the remains of a candle, besides the two grim relics, a seamen's thigh-bone and an officer's ring taken from the shattered skeleton. There is also the narrative of the loss of the *Royal George* bound in two pieces of the wood of the vessel, and a handsome vase made from the timber and guns.

These fragments of a bygone naval disaster, which aroused keen sympathy throughout the Isles when George III was king, bring to mind Cowper's famous poem, "Toll for the Brave."

A much older relic is that of a carpenter's plane found in the wreck of a vessel of the Spanish

Armada sunk in Vigo Bay in 1588—the date of birth of England's navy—and the wheel of a pulley-block recovered after a submersion of nearly 300 years from the *Mary Rose*, which sank beneath the waves in the reign of Henry VIII. None of these can, however, equal in antiquity the Roman tiles and horseman's spur found by divers in the flooded foundations of Winchester Cathedral, where a piece of one of the beech logs, which formed the original subterranean supports laid in 1085, was also discovered.

Another interesting group consists of encrusted bottles, sword scabbards, pieces of African oak, stone shots, a small gun, and a number of bones, including a portion of a skull, recovered from the galleon *Florencia*, the flagship of the Florentine Squadron, sent to assist the Spanish Armada in A.D. 1588, which was blown up and sunk one night by the Highland chief, Donald Glas M'Lean, who was held captive on board.

The *Florencia*, a vessel carrying 56 guns and a crew of nearly 500, had on board treasure estimated to have been worth two millions sterling, and a number of priests in charge of a considerable quantity of valuable church ornaments. Mr. Gush, a well-known Scottish diver, engaged in the year 1874 by the then Duke of Argyll to search for the wreck of this vessel, which sank in Tobermory Bay, Scotland, found many interesting relics, and during recent years his son, Mr. James Gush, has been continuing the work of submarine investigation.

A SUBMARINE WORKSHOP

The helmet and breast-plate room in the works of Messrs. Siebe, Gorman and Co., Ltd., Submarine Engineers to the British Admiralty.

Perhaps the oldest relic of all is a Greek lamp with a sponge adhering to the oil reservoir, found by a sponge-diver off Syra in 140 feet of water. The lamp, which is of bronze, dates back about 300 years B.C. There is also a curious collection of antique water-vessels and small hand-lamps, some of which have sponges attached to them, salved by divers from a submerged island in the Greek Archipelago.

Near to these Greek relics is an officer's sword, which was recovered by a diver in 1890 from the wreck of the French man-of-war, *L'Orient*, sunk by a magazine explosion during the fight with Nelson's fleet at the Battle of the Nile, and a curious old bottle encrusted with innumerable small shells found off the Danish coast in 80 feet of water.

Another item of peculiar interest is one of the seven treasure chests, containing Spanish gold coin to the value of £70,000, recovered from the wreck of the mail steamer *Alphonso XII*, which foundered off Point Gando, Grand Canary, in 162 feet of water. Set in a glass panel fixed to the outside of this chest is one of the actual Spanish gold coins recovered. A Mexican dollar—a specimen of those salved by Diver Ridyard from the *Hamilla Mitchell*—and portions of a marine's musket and carpenter's mallet, recovered after a submergence of 129 years from the wreck of H.M.S. *Edgar*, blown up and sunk off Spithead in the year 1711, may also be seen in this wonderful little museum.

A Submarine Workshop

What is perhaps one of the most curious, and at the same time valuable articles recovered from the sea, is the hunting-knife found by a diver in the wreck of the ship *Cadiz*, which foundered off the French coast, between Ushant and Molène, in 90 feet of water. This knife, which is set with diamonds, has been valued at £7000.

There are numerous other specimens, some depicting the history of diving and diving appliances, others the various submarine industries, but the relics from the deep just described make this collection one of the most unique and interesting in the world.

CHAPTER XXIX

SUBMARINE SIGNALLING

WHAT is submarine signalling? The uninitiated will in all probability associate it with submarine craft only, which is, however, not the case, as it is applicable to every type of vessel afloat. It is one of the latest methods of communication from ship to ship and shoal to ship by means of bell sounds through the silent depths of the sea itself. In fine clear weather, when the vessel's position is known and passing ships and danger signals can be clearly seen, its use is not necessary, but when the conditions are adverse and safety doubtful, as is so often the case during fogs, gales, and snowstorms, the submarine signal relieves the doubt of anxious navigators, who, by its aid, are able to steer their ships clear of treacherous shoals and rocks and avoid the dangers of collision. If submarine signalling apparatus could be applied to icebergs, the great disaster to the *Titanic* would, in all probability, have been averted.

This system has now developed an importance which even wireless telegraphy cannot supplant. In the first place, it can be worked automatically on shoals, buoys, or lightships; secondly, it can be operated by the ordinary crew of a vessel; and,

thirdly, its range and reliability are far greater than any type of atmospheric sound-signalling apparatus yet devised.

In a lecture delivered by the President of the American Company before the Royal Society of Arts in London, the history of the inception and development of this important invention was so interestingly outlined that it may be given here before proceeding to describe the technical details of the apparatus itself, and the systems employed in its everyday use.

The history of the Submarine Signal Company had its birth in 1895, when the United States were at war with Spain. Mr. A. J. Mundy, one of the chief inventors, while sailing from New Orleans up the Mississippi River and sharing the general alarm created by the reported approach of Spanish torpedo-boats, bethought himself of his youthful experience of hearing stones cracked together under water. With the principle of the telephone transmitter in his mind, he speculated whether the microphone could be utilised as a receiver of sounds under water. Not being himself an electrician, he wrote, on reaching St. Louis, to Professor Elisha Gray of Chicago, one of the pioneers in telephonic invention, and enlisted his assistance in devising a practical apparatus. Their investigations were carried on during the summer in the open sea near Boston, and the results obtained were such as to encourage the subscription of ample capital for continuing the work upon an extended scale. A scow

By permission of

The Submarine Signal Co., Ltd.

An Automatic Submarine Bell

The latest form of submarine bell mechanism for attachment to buoys. The right-hand view shows the operating mechanism fitted into the receptacle, which hangs submerged below the floating buoy; the bell being operated by the rise and fall, or movement of the buoy.

large enough to be towed out to sea was built, and from it bells were suspended and rung for experimental purposes. A special shop was engaged and provided with a laboratory, and with all the machinery needed to make any apparatus that the inventors designed. The services of electricians, schooled in telephonic work, were engaged to devise a microphone adapted to use under water. This, in itself, was a most difficult undertaking, and was not successfully mastered for many years. As soon as the organisation of the working force was complete the inventors sought the assistance of leading professors of acoustics, and experts in aerial signals for the sea. But to their dismay they discovered that students of sound had confined their researches to the air and had little knowledge of the various principles of sound in water. Nor were any references to the subject to be found in text-books. The files of scientific publications were searched in vain for records of laboratory experiments with sounds submarine, so that the inventors were face to face with the necessity of depending upon their own unaided investigations. They reasoned quite naturally that whatever was true of sound in the air would be true of sound in water, but experience in time brought the conviction that it was most unsafe to trust to analogies between the two mediums. This made it imperative to construct and operate in the sea a large number of different forms of apparatus, in order to obtain results from which to lay down different

lines of work. Everyone working on actual experiments had to be trained by experience in the sea before observations could be trusted. All this occupied several years, and was attended with great self-sacrifice and devotion to the cause, not to mention personal risk.

It was conclusively proved that water is a better conductor of sound than air on account of its not being subject to such variable conditions. For all scientific purposes the conditions of sea water may be said to remain practically the same, as it has a uniform density at all depths, and submarine sounds travel four times as fast as do those in the air. Giving actual figures, the velocity of sound under water is 4700 feet per second. Below the surface of the sea the sound waves are not diverted or dispersed by the force of the wind, and the tidal currents of the ocean attain no such velocity as pertains to the conditions existing in the atmosphere above, where gales of quite ordinary violence cause aerial currents of great speed, with their attendant noises and strange silences, all assisting to minimise the reliability of the sound signals by air.

For these reasons a submarine bell signal can be heard and located equally well in storm or in calm; but the conditions of the atmosphere are continually changing, and whereas on a calm day the sound of a bell or whistle may be heard up to ten miles distant, a gale will frequently prevent the sound travelling half that distance, especially

in the teeth of the wind. In fact, cases have occurred where steamers have collided although the whistles on both vessels have been continually sounded.

The apparatus used in submarine signalling is divided into three parts, which are best described separately with the aid of diagrams. The sound-producing apparatus (see Fig. 67) consists of a submerged bell, specially adapted to transmit sounds through water. The clapper may be actuated by hand, automatic machinery, electricity, steam, or compressed air, according to whether the installation is on a small sailing ship, a buoy, a lightship, a lighthouse, or a liner. The receiving apparatus, which enables navigators to distinguish the bell sounds at a distance of several miles in any weather, consists of two metal tanks about 10 inches in diameter fitted on each side of the forehold of the vessel, in such a manner that the side of the ship makes one side of the tank (see Fig. 68). A small opening in the top of each tank enables them to be filled with a certain dense liquid, the exact nature of which is a secret. Through the cover which closes this opening hangs the microphones,

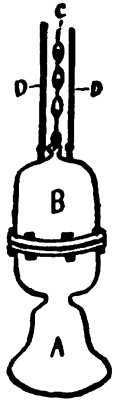


FIG. 67.—Sketch showing exterior of submarine bell. *A*. The bell itself. *B*. Case containing the striking mechanism. *C*. Chain supporting bell. *D*, Pipes conveying compressed air to operate striking mechanism.

or electrical sound receivers, which are suspended in the liquid contained in the tank. It will be seen that there is an entire absence of any projecting apparatus outside the hull of the ship, which would not only be very liable to damage, but also difficult

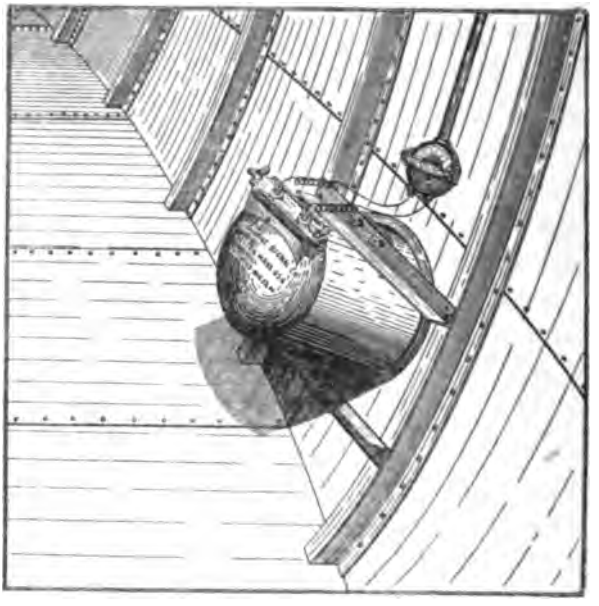


FIG. 68.—Sound-receiving apparatus, fitted on each side of the vessel below the water line.

of access should anything go wrong; and, as there is no connection between the liquid in the tank and the sea, the plates of the vessel's hull are not interfered with in any way. The apparatus can thus be quickly and easily fitted to any kind of vessel.

The sound of the submarine bell passes from the outer water through the wall of the ship into the

liquid in the tank, where it affects the microphone in the same way as an ordinary telephone is affected by the sound of the voice.

The microphones in the port and starboard tanks respectively are connected by wires, which pass through a battery, to the *direction-indicator* and receiving telephones fitted in the chart-house, or other position close to the bridge (see Fig. 69). The direction-indicator is a circular metal case, some nine inches in diameter, fastened, as a clock might be, to the chart-room wall. It has a switch which is so arranged as to connect either the port or starboard microphone with the ear-pieces or receivers, which are similar to those of the ordinary telephone. The dial of this indicator also discloses on which side the telephones are connected, and is illuminated at night by a small electric lamp.

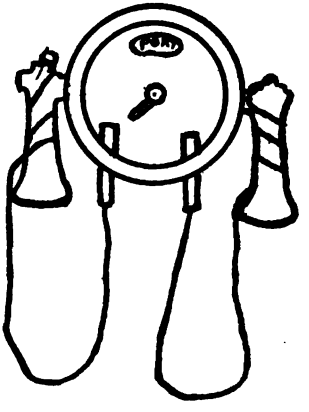


FIG. 69.—Direction-Indicator, by means of which the captain of a vessel can tell the direction of the submarine bell signal.

Either of the receivers may alone be used to listen to the submarine bell marking a shoal or approaching ship, or, if the sound is faint, both may be utilised, one being placed to each ear.

It will be observed that the sound will be heard most distinctly on the side of the vessel nearest, and the captain can thus discover the exact position

of the bell and steer a course accordingly. If it is desired to head the vessel direct for the bell, the moment the sound is heard, the vessel should be turned towards it. Listening with a receiver to each ear the bell will first be heard on one side only, then by turning the vessel in this direction until the bow crosses the line of actual direction the sound becomes equally distinct on both sides and proves that the vessel is heading direct for the bell. The course can then be kept by compass. A reference to Fig. 70 will make this, and all manœuvres by submarine bell signals, quite clear.

I have dealt at some length upon the apparatus and methods of submarine signalling because of its growing importance to navigation; and now that the *modus operandi* has been made plain the systems in use must be described so that the reader may be familiar with the working of this great aid to navigators (see Fig. 70).

The stationary signal for warning vessels of the proximity of rocks, shoals, harbours, or the direction of a channel, consists of a submerged bell of a particular design so that long range sounds may be produced. The bell is so constructed that the clapper strikes after regular intervals of silence, and these intervals can be arranged, as to duration, to form a code of signals, the bell striking a given number in a given space of time, which identifies the exact location as marked on the chart. For instance, if lightship *A* marks one end of a sand-

bank, its submerged bell may strike ten times a minute, and the bell on lightship *B*, marking the other end of the bank, only five times a minute.

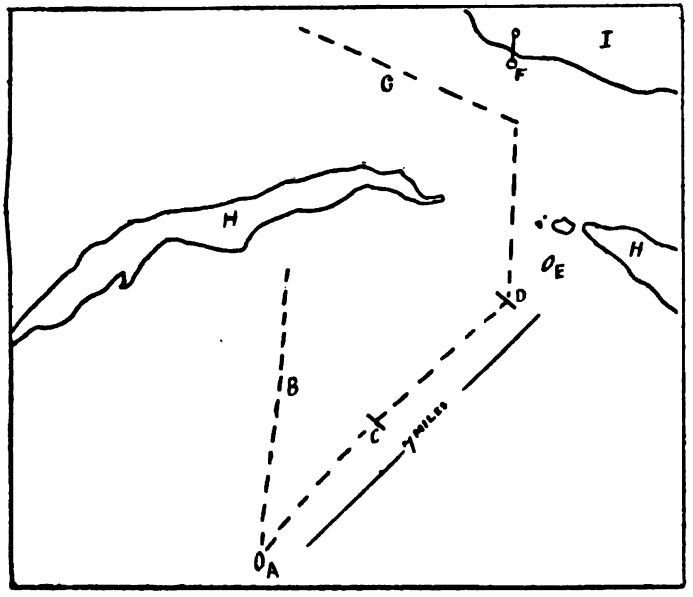


FIG. 70.—Chart showing a vessel being navigated in a dense fog by submarine signals. *A*. Steamer going ahead on course *B*, when the submarine signal from the lightship *E* is heard. According to the ship's chart she is immediately headed for the bell instead of continuing on the dangerous course *B*. At the point marked *C* the ordinary atmospheric signal on the lightship is heard, but, as will be seen, this would not have prevented the steamer continuing on course *B*, and striking the dangerous shoal *H*. At point *D* the steamer sees the lightship's light, and, turning, steams past (according to chart). The submarine bell operated from the shore station *F* is now heard, and the steamer heads for this, turning out into the open sea when the sound of this bell proclaims the shore to be quite close.

It will therefore be seen how easily the position of a bell, whether it be on a buoy, lightship, or fixed to the bottom of the sea, can be identified

by approaching vessels fitted with the receiving apparatus.

Stationary signals usually have bells of about 15 to 18 inches in diameter, and can be heard within a radius of six miles, but they have been frequently distinguished fifteen miles distant. The submarine bell in one of its applications is suspended in the water from a lightship and operated at will by automatic machinery, steam, or compressed air controlled by the crew in a similar manner to the fog-horn. In another case it is suspended from a buoy and rung automatically by the motion of the waves; and, again, it may be held on the bottom of the sea by an iron tripod and connected by an electric cable to a lighthouse or other station on shore.

Its application to moving ships is equally as varied, it may be fitted in the fore-peak of a submarine boat, in the hold of a liner or sailing ship, or simply hung over the side of a fishing vessel and rung automatically by the rocking of the boat. In the latter case, presuming it to be one of a fleet, the parent vessel, or "admiral" as the leader is called in nautical parlance, if fitted with the receiving apparatus, will have no difficulty in "picking up" or going to the aid of any of its small dependants.

Inter-communication between ship and ship requires specially designed submarine bells, as the sound must not, for obvious reasons, be confused with those of stationary signals, and in this case

it is also necessary that no fixed arrangements as to the number or duration of strokes should be made, as various signals in morse or private codes may be required for communication.

The general public scarcely realises the tremendous destruction of life and property taking place each year at sea, and the fog fiend, of which the submarine bell is the avowed enemy, is responsible for so large a percentage of these accidents that the benefits of submarine signalling are being very generally recognised, as is proved by its adoption by the marine authorities of so many countries.

The United States Government was the first officially to take up submarine signalling and apply it to battleships, submarines, and lightships, but other governments soon followed America's lead, and a very large number of both English and Canadian, as well as German lightships are now fitted with bells. The Cunard, White Star, and North-German Lloyd Companies have also equipped many of their largest Transatlantic liners with the complete installation. Nearly all the important lightships guarding the British, Canadian, and United States coasts are fitted with submerged bells.

It will be instructive as well as interesting to give here a few examples of submarine signalling as related by commanders of large and well-known ships. On one occasion the captain of the *Lucania* (Cunard Line) heard the Nantucket shoals submarine bell when 7½ miles distant, but could no

hear the air-whistle until she had approached to within 2½ miles of the shoal. She was steered continually by the bell. The captain of the *Coronia* (belonging to the same Company) heard the Nantucket bell at 4¾ miles, and reports making all three lightships marking the entrance to New York—the Nantucket, Fire Island, and Sandy Hook—by submarine signals. One of the greatest distances at which the bells of these lightships have been heard was reported by the captain of the *Oceanic*. The vessel was travelling in a thick mist, when he heard the Nantucket bell very distinctly at 10¾ miles. In clear weather on the same day the Fire Island bell was easily distinguishable at 7½ miles, and the Sandy Hook bell at 5 miles.

Curiously, submarine signals can be heard at a greater distance in thick weather, when they are most required, than in clear, the reason for this being that not only are the senses of those in command of vessels strained to the utmost in the anxious times of fog, but fog itself appears to dull, if it does not actually shut out, all atmospheric noises, hence sounds passing through a different medium become sharper and distinguishable at greater distances; furthermore, a vessel, especially if she be a fast liner, is usually travelling at a reduced speed in a thick fog, and the decrease in the speed causes a decrease in the noise and vibration occasioned by the engines and sea-wash against the vessel's side. Submarine bells can always be heard

at a greater distance, or more distinctly, if the vessel is stopped for a few minutes.

The *Kaiser Wilhelm II*, *Bremen*, *Deutschland*, and *Amerika* of the North German Lloyd Line, as well as the steamships of innumerable other lines, have also furnished exceptionally good reports as to the great advantage the submarine bell possesses over atmospheric signals. The *Amerika*, for instance, reported that she *saw* the Fire Island lightship at a distance of 1½ miles, but could not hear a sound—the submarine bell had, however, been distinctly heard 4 miles away. The captain of the *Bremen* declared that on one occasion he would have missed the Nantucket shoals lightship entirely but for the submarine bell, the latter being heard thirty-five minutes before the whistle when steaming at 8 knots in a fog.

The many reports from both steam and sailing vessels, of which the above are but a very few picked at random from the number before me, are without exception entirely favourable to the system. One well-known captain remarks that he often hears the bell when there is too much noise by wind and sea to hear the whistle.

There are many cases of sailing vessels not being fitted with the apparatus for receiving submarine signals obtaining the sound through the sides of the ship. This substantiates the statement made that even vessels not equipped with the receiving apparatus may obtain warning when danger approaches, so long as the bell is working.

Submarine Signalling

The United States was, to a large extent, instrumental in bringing submarine signalling within the realm of practical navigation, but this was not before exhaustive experiments had been made as to the best method of receiving the bell sounds on board a ship travelling at high speed.

It was discovered by an elaborate system of experiments that if the tanks were filled with a solution denser than sea-water, and the microphones adapted to receive high-pitched sounds, the submarine bells were more easily heard and located. For sending signals from vessels, the bell is suspended in a tank filled with water, and situated as deep as possible below the water-line in the fore-peak. The bells for this purpose vary in weight from 100 to 150 lb. The best form of bell was also a matter of gradual evolution, and the sound bowl, or lip, is now constructed several inches thick, and when struck has a high-pitched musical note, which is found to be of the greatest efficiency for signalling beneath the sea, although unsatisfactory in the air.

The fact that the distance and exact direction at which ordinary atmospheric signals can be heard and located is trebled and placed on a more reliable basis by this new submarine system is leading to its general adoption throughout the world.

CHAPTER XXX

ITEMS OF SUBMARINE INFORMATION

MUCH submarine information that is really both interesting and useful cannot be classified under any single heading, and I therefore propose giving here a selection of data in separate paragraphs.

THE HEIGHT AND FORCE OF WAVES

The height of waves and the force they exert is a factor of considerable importance when planning the erection of breakwaters and piers. It will, however, be easily understood that waves vary, in height, force, and rapidity, to such an extent that any basis for exact calculation is impossible. It has been proved that the highest waves are not always the most powerful, and that the greater the power the slower the succession. At Dover (England, S.E.) the greatest height recorded during the past twenty years is 18 feet from trough to crest, whereas on the north-east coast of England and Scotland waves reaching 40 feet in height have been observed. The average height during violent gales along most of the exposed portions of the British and American North-Atlantic coasts may be reckoned at from 20 to 25

feet, and the force exerted from ½ to 1 ton per square foot, but cases have occurred when both the height and force have exceeded this estimate by as much as 50 per cent.

At Peterhead, some years ago, concrete blocks weighing 41 tons apiece were displaced at a depth of 37 feet below the surface (low water), showing the great depth at which wave disturbance sometimes occurs. On the same occasion a section of concrete wall weighing 3300 tons was moved *en masse* about 2 inches without being dislocated. It has been estimated that the force necessary to have effected this could not have been less than 2 tons per square foot, exerted over the whole section of wall simultaneously. The Colombo breakwater suffered in a similar way, the sea-section of the wall, 150 feet long by 28 feet broad, being moved 15 inches.

Work done by Pneumatic Tools

The time occupied in pneumatic drilling is of considerable importance in rock-blasting and wreck-dispersing, hence a few general facts may not be out of place here. When drilling into mild steel, a 1-inch hole can be deepened at the rate of 1 to 1¼ inches per minute, while a pneumatic borer will drill the same sized hole in wood at the rate of from 3 to 6 inches per minute, according to the nature of the material. A pneumatic tripod rock-drill will bore a hole 1½ inches in diameter at

the rate of 1 inch per minute in moderately hard rock. In deep water, however, not more than half this speed is likely to be obtained.

Rock Removal without Explosives

We have already seen that the most usual method of removing rocks obstructing maritime highways is by drilling and blasting; there is, however, another system—the Lobnitz—which is independent of explosives, and is being very successfully employed in many parts of the world. The initial cost of the plant required makes the adoption of this system only justifiable where large quantities of rock have to be broken up.

The plant usually consists of a barge fitted with one or more *cutters*, or pointed steel bars, weighing from 6 to 15 tons, which are connected from their butt-ends by wire ropes passing over upright derricks to steam winches (see Fig. 71). The principle of working is simple, and much resembles that of a pile-driver. The winch hoists the heavy cutters until their points of armour-piercing steel are from 10 to 20 feet above the submerged rock, they are then released, and fall by their own weight, striking the rock with their sharp points and splitting it into fragments.

A cutter weighing 5 tons dropped 20 feet gives a striking force of 100 foot-tons, which is concentrated on the point of the *needle*. From this it will be realised that even the hardest rock is so

broken by repeated blows regulated to fall on precisely the same spot. It has been found, however, that a heavier cutter with a shorter drop is more effective, hence for breaking granite a 15-ton bar with a 10-feet drop is recommended, but for pul-

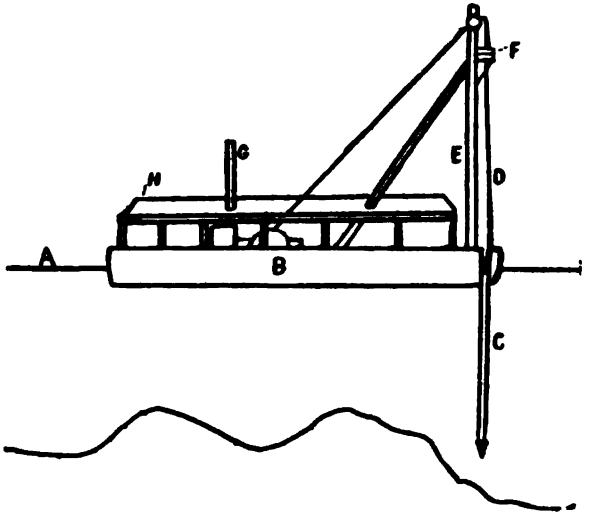


FIG. 71.—Barge fitted with a submarine rock-cutter. *A*. Surface line. *B*. Barge. *C*. Heavy steel bar with detachable point or needle. *D*. Wire rope to steam winch. *E*. Upright derrick. *F*. Platform from which the *cutter* may be aimed. *G*. Funnel of boiler operating winch. *H*. Permanent awning (used in the Tropics).

verising ordinary rock in comparatively shallow water, a 6-ton bar with a 10-feet drop is equally as effective.

The approximate cost of a barge fitted complete with a single cutter is about £5000, and the speed of work 150 blows per hour, breaking on an average 10 cubic yards of hard rock.

Items of Submarine Information

The Submarine World

The depth to which daylight penetrates in water varies considerably. In some of the Scottish lochs the diver is plunged into a pall-like blackness when but a few feet below the surface, while in tropical seas a soft light usually penetrates to a depth of over 200 feet. In parts of the Amazon river the submarine daylight is of a peculiar amber hue, while in some of the streams and lakes of British Columbia it is of a steely-bluish tint. Off the Rock of Gibraltar objects can be clearly seen at a depth of 150 to 200 feet, but in the Thames, above Gravesend, so muddy is the water that it is impossible to see 2 feet ahead even with the aid of a powerful submarine electric lamp.

The scenery of the under-seas also varies to such an extent that no general description is possible. In some tropical waters, notably around the coral islands of the Pacific, the marine flora is more beautiful than anything that grows on land. This is also the case in certain parts of the Caribbean Sea, where anemone caves exhibit a wonderful medley of the most exquisite and delicate hues. The sunlight penetrates into these rocky recesses with a soft crystal-like radiance, which shows to perfection the spotless purity of the white, pink, pale-blue and green flowers, and weed-forests of the silent unexplored ocean depths.

Items of Submarine Information

Submarine Photography

Submarine photography offers a wide and interesting field for research. A number of experiments have already been carried out with varying results. In tropical waters some remarkable pictures of coral reefs, sponge and oyster beds, old wrecks, and exquisite submarine flowers have been obtained, while off the American and English coasts a few really clear views have also been taken.

There are some views extant, taken off Plymouth (England), at a depth of 60 feet, in which the objects (pipes) show clearly although some distance from the camera. I have several views taken through the observation glass of a submarine showing the sea-bed for a distance of 30 to 40 feet ahead, as well as some excellent views of objects and scenery obtained with the aid of the diving-dress.

For submarine use the camera is fitted into a large watertight metal case, and it is advisable to use a weighted stand to which the camera can be easily fixed by the diver, as it is almost impossible, where there is any movement of the water, to keep sufficiently still to take a clear picture without it. A powerful lens and a long exposure are absolutely necessary, even where the light appears to be fairly good.

The Effect of Compressed Air on the Voice and Hearing

When speaking through the telephone to a diver in very deep water, the effect of compressed air on the voice is most noticeable. At quite moderate depths it has a strained sound which, however, does not increase with the descent, but changes to a nasal twang; this, in very deep water, becomes "Punch-like," and extremely funny to a listener on the surface. By connecting two divers—one with a deep and the other with a higher toned voice—and listening with both ears at the respective receivers while a conversation is taking place, an almost perfect "Punch and Judy show" can be heard. The responsibility for this curious phenomenon rests on the density of the air, which increases with the pressure, and in this connection it is interesting to note that a diver cannot whistle when in deep water, owing to the density of the air hindering the vibration of the lips.

Although compressed air has little or no effect on the sense of hearing, the pressure on the ears may be very painful and even dangerous; the reason for this being that the tight skin covering known as the "drum" of the ear is forced in by the undue pressure of the external air. This, however, only occurs when the tiny tube leading from behind the ear-drum to the nose becomes blocked by cold or other cause, for when this tube is cle

the air pressure is communicated by way of the nose to the back of the ear-drum, and therefore the pressure on the inside is equal to that on the outside.

It is to open this little tube when it has become blocked that divers, when descending, make frequent halts to swallow saliva. The action of swallowing usually opens the tube, but if from any cause this should not be the case, the pain occasioned by the pressure increases, and an immediate return to the surface is imperative.

The Danger of a Fall in Shallow and Deep Water

Few people realise the terrible danger which often threatens a diver even when working in shallow water. Let us take, for example, the case of a diver working a few feet below the surface on a slung spar or stage cleaning a vessel's bottom. Should he by some mischance, or through carelessness on the part of the surface attendant holding the life-line and air-pipe, lose his footing and fall off the stage into, say, 30 feet of water, he will in all probability be killed, or at least severely injured, by the terrible squeeze to which he has been subjected. At that depth the total pressure would be double what it was near the surface, and the unfortunate diver would thus have suddenly applied to every square foot of his body an additional pressure of about 2000 lb. The effect would be

terrible. The helmet being rigid, his body would be crushed into it with terrific force. Exactly what injuries would be sustained, it is impossible to say; death is probable, and severe injuries, accompanied by bleeding from the lungs, mouth, and nose, almost a certainty.

Curious as it may seem, should a similar fall happen to a diver working in 150 to 160 feet of water, the danger would be much less, as at that depth the difference in the pressure would be far less—in other words, a fall of 30 feet would then only increase the pressure to which the diver was subjected in the proportion of seven to six, instead of doubling it, as was the case near the surface. From this it will be seen that in deep water a short fall is much less serious than in shallow water.

CHAPTER XXXI

SUBMARINE ENGINEERING OF THE FUTURE

To forecast the progress of events is always an exceedingly difficult and risky procedure, and especially is this the case when it relates in any way to the development of science and engineering, which depends almost entirely upon the crop of inventive genius, a notoriously fickle product; for who shall say that the world will benefit during the next half century by the ingenuity of a second Edison, Marconi, Parsons, or, more appropriately, another Siebe, Holland, or Lake? Yet close acquaintance with past achievements and present needs leads one almost subconsciously to foresee future possibilities.

In the domain of diving we already have practical indications of wider scope and means of access to greater depths. Professor Leonard Hill, who for many years has been devoting much time to experiments with compressed air, has found that man can breathe air under much greater pressure than was generally supposed without danger or discomfort, providing that the process of compression and decompression be effected very slowly. The practical importance of this is shown in the special bell devised by Messrs. Siebe, Gorman & Co., at

the suggestion of the Professor, by the aid of which divers will be able to work with safety for lengthened periods in depths up to 240 feet.[1]

The bell, which is provided with an air-tight compartment and furnished with electric light, and

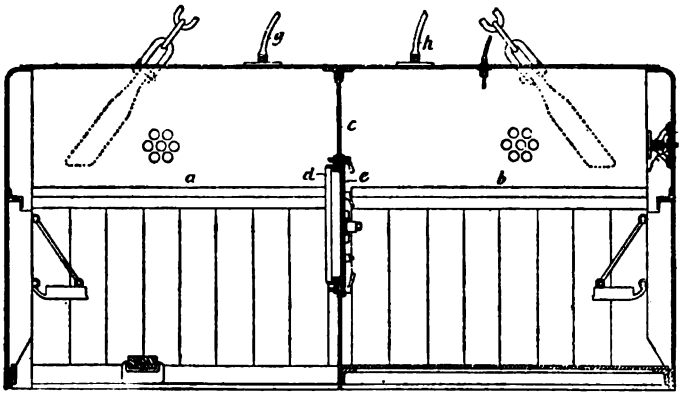


FIG. 72.—Section of a combined diving-bell and decompression chamber. This form of bell, used for diving in very deep water, is divided into two compartments by a partition, *c*, one of the chambers, *a*, being open at the bottom in the usual way, the other chamber, *b*, being entirely closed. The partition is provided with a manhole, *d*, and cover, *e*, which can be opened or closed from either side, and with a valve, *f*, for allowing the pressure in the closed chamber to be gradually reduced. Each chamber is provided with compressed air through the pipes, *g* and *h*.

telephonic communication with the outside, is lowered to the diver when at a great depth, so that when he has finished work he may shut himself in the compartment, remove his diving dress, and take a rest; the pressure of air in this compartment

[1] An excellent treatise dealing scientifically with the Physiology of work in compressed air is *Caisson Sickness*, by Leonard Hill, M.B., F.R.S., in the International Medical Monographs, published by Edward Arnold.

being regulated to that in which the diver has been working. The bell is then hauled up on to the deck of the salvage vessel, and the pressure of air in the compartment allowed to slowly decrease until it becomes normal, when the diver may be released from his temporary confinement without risk of injury; the time required for this process of slow decompression being from one to two hours, according to the pressure or depth. When the diver is hauled up from a depth of 240 feet he must sit in this compartment for fully two hours, while the pressure is being slowly reduced, before he can emerge with safety into the ordinary atmosphere. A deadly form of paralysis, called *diver's bends*, which causes a man to literally swell and burst, would probably result from a quick rise to the surface after being subjected to the pressure which obtains in a great depth of water.

The practicability of several submarine pearlers and salvers has been vouched for by many experts, and what may be termed the mechanical diver is, therefore, another direction in which we may look for future developments.

Turning to submarine boats proper, we find that three problems present themselves for solution: a means of vision when submerged, a motive power and engine capable of propelling these vessels at an increased speed both above and below water, and a perfect system of wireless communication between submarines and surface vessels. It has already been shown how these disabilities are overcome in

present-day boats, but it cannot be said that any of these problems have been solved. In the first instance a submarine would be blind were it not for her periscopes, which, projecting only a little above the surface, become submerged and useless when the vessel sinks deeper than a few feet or the sea is rough. The engine difficulty is circumvented by the use of two different motive powers and two sets of engines, thus occupying more space and adding more weight than is warranted by the driving force actually derived. Communication with submarines when cruising under water is maintained by signals, seen through the periscope; by gunfire, which is easily heard; and with the aid of submarine signalling apparatus. The two former methods need scarcely be considered, for although practicable in peace they would be quite impossible in time of war, besides they do not provide a means of intercommunication between submarines. The latter method may act remarkably well in peace manœuvres, but as all these vessels are built for war, and it is quite certain that neither a submarine nor its attendant warship would run the risk of notifying its position to the enemy by the clanging of a submerged bell, which is specially designed so that its sound may penetrate through the surrounding sea for many miles, this system is worse than useless, for it adds weight without giving its equivalent in fighting value.

That which is perhaps coming most rapidly within the realm of practicability is the submarine

battleship. Even as the successful construction of the "Dreadnought" opened the last era in naval warfare, so will the submarine or sub-surface cruiser and battleship be the next revolutionising agent in the domain of sea-power—but this is scarcely likely to pertain until after the next "Trafalgar."

This brings us to yet another promising field, for every new weapon of attack is sure to be quickly followed by a counteracting means of defence. Experiments are being carried out with a device for use on surface vessels for detecting the approach of submarines and torpedoes and locating their position. This will, before long, probably lead to the use of the wireless torpedo, propelled and guided by electric impulses sent through air and water, for use against these unseen foes, no longer secure by their invisibility.

Turning to the more peaceful work of submarine construction, we find the sinking of cylinders, and even concrete blocks, into sandy beds being accomplished by suction-pumps, and dangerous sand-banks being cleared away by the same means. Even disintegrated rock can now be sucked up in this way at the rate of over a ton a minute. A certain increase in the capacity of suction-pumps will greatly facilitate many hitherto difficult submarine operations. The discovery of a really effective means of seeing through moderately clear water will also obviate the necessity of descents by engineers and divers for the purpose of making

submarine examinations of breakwaters and piers, although it is scarcely possible to conceive how an instrument can be devised which will enable a person to see through really thick water, such as is found in harbours, which is made so by clouds of floating particles; but the X-rays have destroyed all belief in the impossible invention of this description. Concrete blocks will doubtless soon be turned out "ready-made" by machinery at an astonishing speed; while the already revolutionising influence of pneumatic tools will continue until the diver does little more than stand still and direct machinery operated from the surface.

Whatever may be predicted it is, however, certain that it will fall far short of actualities, for who could have foreseen the wireless telegraph, the phonograph, the aeroplane, the submarine, the X-rays, and the electric light?

Modern submarine engineering as a science is as yet in its infancy—but "the child of to-day is the man of to-morrow."

APPENDIX I

LOG OF U.S. SUBMARINE TORPEDO-BOAT *HOLLAND*[1]

6th November 1897

2 hrs. 19 min. 00 sec.	Start for official run.
2 „ 26 „ 00 „	Amidship tanks filled and conning-tower closed and ran awash.
2 „ 28 „ 30 „	Dive. Revolutions of propeller, 226 per minute.
2 „ 35 „ 00 „	Got ready to fire torpedo.
2 „ 41 „ 00 „	Rose to surface.
2 „ 42 „ 00 „	Fixed torpedo. Turned and headed for return run.
2 „ 43 „ 12 „	The dive made. Vessel steered well in both vertical and horizontal planes.
2 „ 56 „ 10 „	Rose to surface.
2 „ 57 „ 00 „	Open turret. Stopped. Two air-tanks down to pressure of 1300 lbs.

Commander Emory and one of the crew left the boat. Their places were taken by Naval-Constructor Capps and Lieutenant-Commander Henderson.

[1] It was official trials like these, conducted in the United States, France, and Great Britain about this period, which caused the addition of submarine flotillas to the world's navies.

3 hrs. 20 min. 00 sec.	Closed turret and went ahead awash.
3 „ 35 „ 00 „	Dive. Ahead full speed and fired torpedo at submergence of 5½ feet. Rose to surface, and the members of the Naval Trial Board left the boat.

Maximum inclinations during these runs—10 degrees by the head, 9 degrees by the stern.

Voltage at start, 125; at finish, after the surface run, at 3 hours 30 minutes P.M.—123.

The many very successful trials of the submarine torpedo-boat *Holland*, and the favourable opinions expressed by most of the naval experts who watched closely the performances of the boat, caused an order for six more submarines of the same (improved) type to appear in the Naval Estimates for the following year.

APPENDIX II

TRIALS OF THE U.S. SUBMARINE *OCTOPUS* BEFORE NAVAL TRIAL BOARD

President, Captain MARISE, U.S.N.

Speed Trials

(Newport, R.I., May 1907)

THE submarine torpedo-boat *Octopus* has now completed all her speed trials, and the following shows the result :—

Maximum trial speed on the surface, over measured mile, 11 knots.

The boat had the benefit of the tide, which, however, was running weak.

Maximum trial speed awash, 9.98 knots.

Tide in favour.

Maximum trial speed at a submergence of 10 feet, 8.90 knots.

Five feet of periscopic tube showing above water. Tide in favour.

Manœuvring Tests

(Newport, R.I., May 1907)

The *Octopus* made two "porpoise" dives. Went down at an angle of 8 degrees to a depth of 25 feet in 40 seconds.

Returned to surface for observation of 5 seconds, then dived again to same depth in 43 seconds.

Proceeded for ten miles partly trimmed for diving,

then fully trimmed, and went down to a depth of 20 feet in 1 minute and 30 seconds.

Accident Tests

(Not really required by U.S. Government)

These tests were carried out by the contractors with a view to proving that the *Octopus* is especially adapted for warfare, and to accentuate her worth.

1st Demonstration.—Both petrol engines coupled to one propeller-shaft, and using only the one screw, the *Octopus* made 7.92 knots against wind blowing 15 miles an hour and choppy sea.

2nd Demonstration.—One petrol engine broken down, accumulators run out, and one propeller damaged. Thus, with one engine, coupled to single propeller-shaft, the *Octopus* made 7.25 knots.

Submergence Test

(Narragansett Bay, Newport, R.I., May 16th, 1906)

Octopus rose from sea-bed (28 feet of water), where she had remained for 24 hours, with 15 men on board.

The foul air had been pumped out twice during submergence; and it was estimated that about 40 per cent. of the stored air had been used (?).

Submarine signals were successfully used during these tests.

Torpedo-Firing Trials

(Newport, R.I., May 1907)

Targets.—Two small boats, moored 300 feet apart (average length of battleship).

Type of torpedoes used.—(Old) Mark 1 Whitehead.

First discharge, from port tube:—

Octopus travelling submerged at 8½ knots proceeded towards target. Torpedo launched at a range of 1100

yards. The old and unreliable Mark 1 pattern were used for these tests, and the first torpedo discharged from the *Octopus* headed straight for the target for about 600 yards, and then broached—turning to the right at an angle of 90 degrees. The torpedo sank, and was not recovered. It was pronounced a "crank" projectile.

Second discharge, starboard tube :—

Torpedo caught at muzzle of expulsion tube, and hung. Buoyancy chamber of torpedo badly broken ; and projectile only released after much delay.

Third discharge :—

Torpedo ran straight for target, but did not travel as far, coming to surface after running 600 yards.

Later.—Torpedo discharged from starboard tube successfully, but projectile again fell short of target.

Deep Sea Submergence Test

(Six miles off Boston Lightship)

The water-inlet valves of the ballast tanks of the *Octopus* were opened.

Crew left the boat, and the conning-tower cap was screwed down.

The submarine was then lowered by cranes and steel hawsers to a depth of 200 feet, at which depth the pressure on the hull of the submarine was 86½ lbs. per square inch.

The *Octopus* stood the pressure well, and did not develop the smallest leak.

Open Sea Trial

(Off Boston Lightship)

The submarine *Octopus* cruised for five hours off Boston Lightship during rough weather, and proved her good qualities for surface cruising.

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